AUGUST, 1961

Welding Journal

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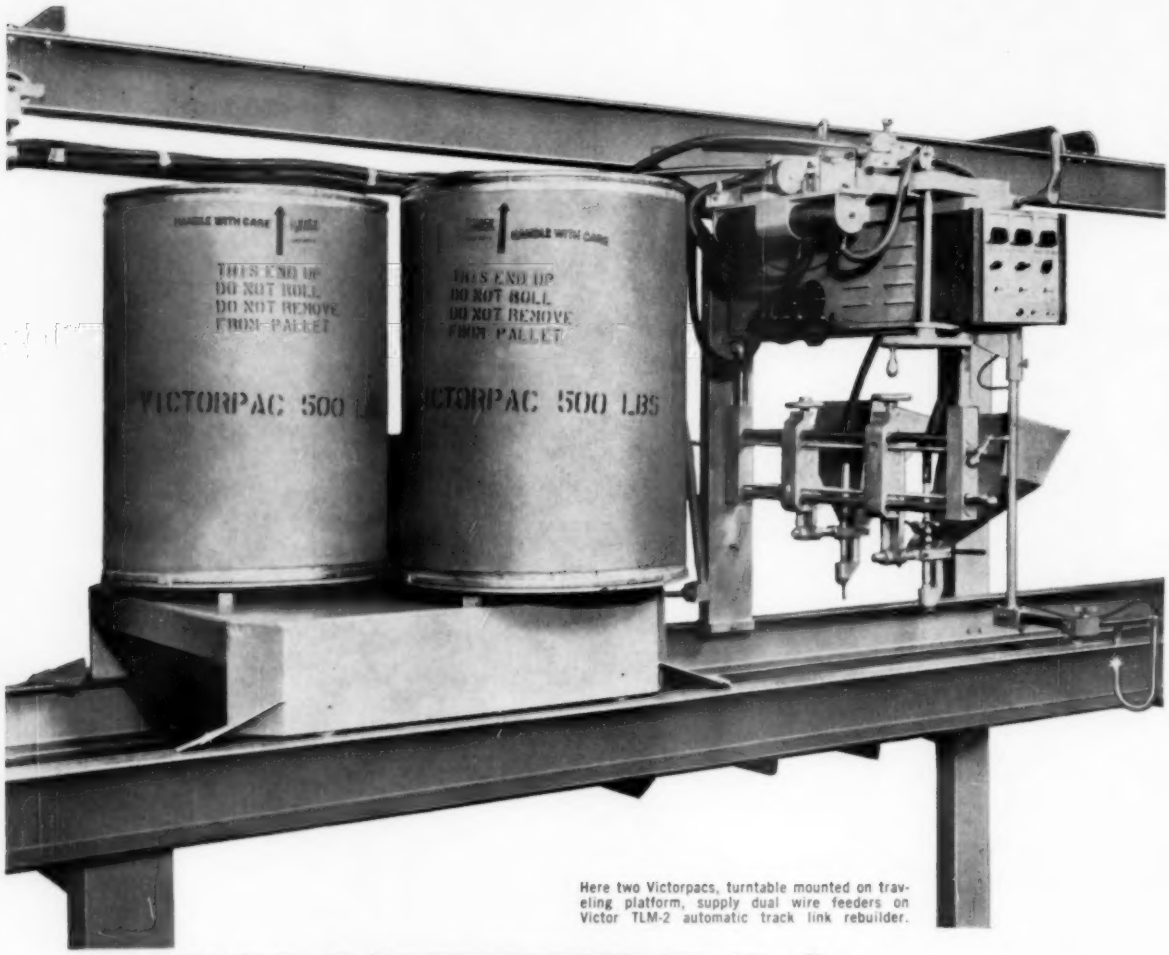
OFFICIAL PUBLICATION OF THE AMERICAN WELDING SOCIETY



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PRESS-TIME NEWS ...about ...People ...Welding ...Products

Sun Shipbuilding Elects Holzbaur

A. A. Holzbaur AWS was recently elected vice president in charge of operations at the Sun Shipbuilding & Dry Dock Co., Chester, Pa. Mr. Holzbaur was previously general superintendent. In addition, Mr. Holzbaur is a former member of the AWS Board of Directors, having served from 1958–61. His affiliations include membership in the Society of Naval Architects and Marine Engineers.

Other developments at Sun Shipbuilding were the retirement of R. L. Burke as president and W. Craemer as secretary and treasurer. Succeeding Mr. Burke is P. E. Atkinson while C. H. Doyle succeeds Mr. Craemer. R. Galloway is vice president in charge of sales, and C. Zeien has become vice president in charge of engineering. J. G. Pew, Jr., a vice president and member of the board, is now also in charge of public relations.

New ASTM National Officers

The election of the new national officers for the American Society for Testing Materials was recently announced during the 64th Annual Meeting of the Society in Atlantic City, N. J.

Miles N. Clair, president, The Thompson & Lichtner Co., Inc., Brookline, Mass., was elected president of ASTM to serve for a one-year term, and Alfred C. Webber, E. I. duPont de Nemours and Co., Inc., Wilmington, Del., was elected vice president. R. Wade Seniff, The Baltimore and Ohio Railroad Co., Baltimore, Md., will continue as senior vice president.

Arcair Starts New Building

The Arcair Co., Lancaster, Ohio, has started construction of a new plant which will triple existing facilities. Completion is scheduled for August.

The new, modern one story structure will be situated on an 8-acre site, located 2½ miles north of Lancaster on U. S. Route 33. It will provide complete manufacturing, office and warehouse facilities and will include enlarged laboratory facilities for the company's research and development program.

Shumaker Nominated for ASME Presidency

Clifford H. Shumaker has been named to serve as president of The American Society of Mechanical Engineers. His nomination was announced at the recent Summer Annual Meeting of ASME at the Statler Hilton Hotel, in Los Angeles.

Together with six vice presidents and four directors, also nominated, Professor Shumaker will begin his term in June of 1962, following a mail ballot of the membership this fall. Professor Shumaker is chairman of the Department of Industrial Engineering of Southern Methodist University, Dallas, Tex.

Picker X-Ray Opens New Headquarters

The Picker X-Ray Corp. of White Plains, N. Y., a manufacturer of non-destructive equipment used by the welding industry has moved to a new headquarters office building.

The air-conditioned two-story structure contains 47,000 sq ft of floor space. It will house approximately 150 executives and staff personnel of Picker. It also contains a classroom for 100, an employee dining room, offices and facilities for demonstrating new apparatus. The brick and plate glass building, designed in modern architectural style, is located on a 10-acre site where Picker planted more than 4000 trees and shrubs.

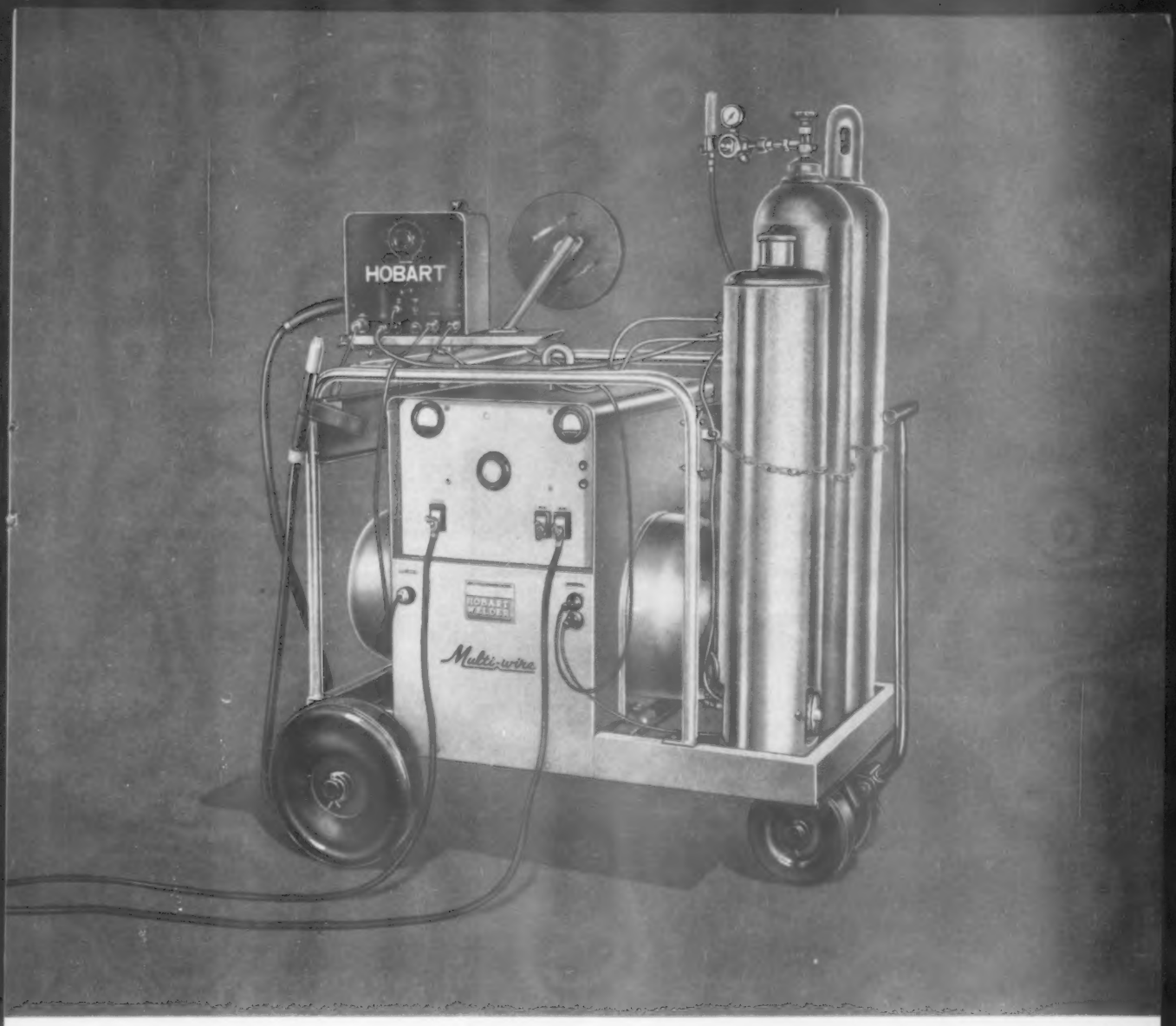
The new address of Picker in White Plains is 1275 Mamaroneck Ave.

U.S. Firm to Exhibit in Poland

Samples of the latest ultrasonic welding equipment made in the United States have been contributed by Gulton Industries, Metuchen, N. J., to the U. S. Exhibition at the 30th International Trade Fair now at Poznan, Poland.

SEMINAR FOR U. S. CORPS OF ENGINEERS

Scene from one-day hardfacing seminar which was recently conducted for the U. S. Corps of Engineers at the Lincoln Electric Co., Cleveland, Ohio, under the guidance of A. F. Boucher (without jacket in center)



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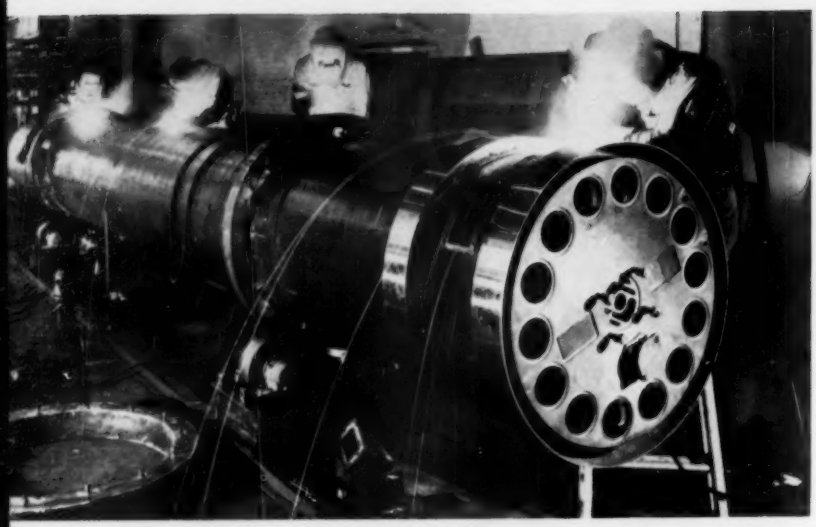
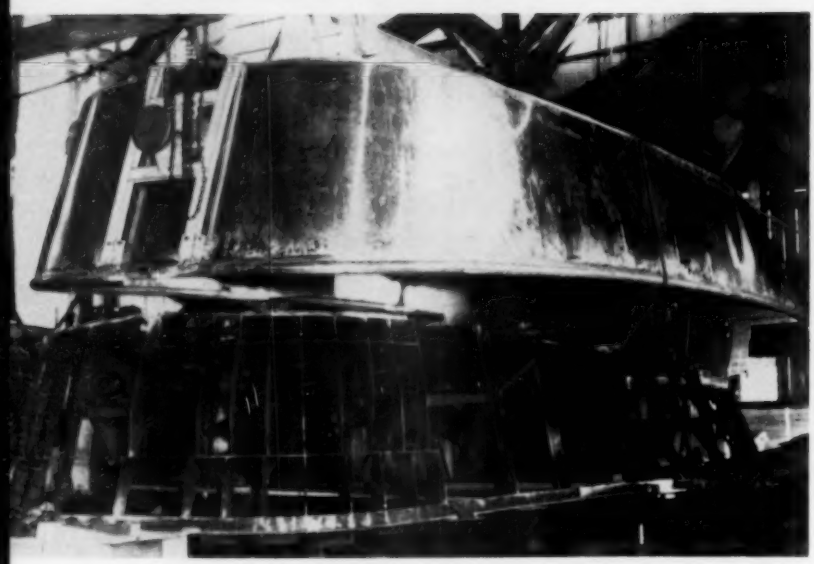
WELDING ZONES



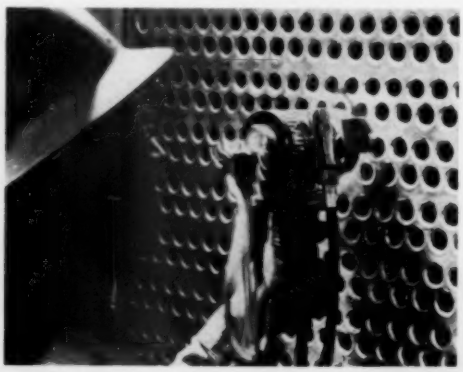
Seam-welding operation on a 38-in. diam by 30-ft long water tube cooler fabricated by Custom Products, Inc. (Courtesy Joseph T. Ryerson & Son, Inc.)



Aluminum hull of a 32-ft gillnetter, used for fishing in Alaska, after completion by gas metal-arc welding in five 8-hr shifts in the Matsumoto Shipyards, North Vancouver, B. C. (Courtesy Kaiser Aluminum & Chemical Corp.)

Giant segmental globe being tack-welded for fit-up prior to shipment from Lukens Steel Co. The vessel, to be used to store liquid oxygen, measures 128 1/2 in. ID and is 1/2 in. thick

Lightweight automatic welding gun being used in the construction of the nuclear electric generating station of Consolidated Edison Co. of New York. (Courtesy Revere Copper and Brass, Inc.)



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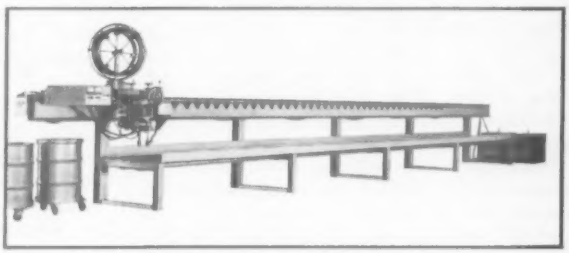

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WORLD-WIDE WELDING NEWS

by Gerald E. Claussen

AUSTRIA

The November 1960 issue of *Schweisstechnik* (Vienna) describes gas-shielded welding of mild steel with special electrodes and Coxogen, a half-and-half mixture of argon and CO_2. This mixture was found to reduce the porosity commonly found in welds deposited under argon.

BELGIUM

The Arcos Magazine No. 145 for 1960 describes internal pressure fatigue tests at Ghent University on three sections of oil piping 11 ft long, about 10-in. diam, 0.295-in. wall. Each section contained a number of radiographed welds made with covered electrodes in API joints. No weld failed during 50,000 pulsations from 280 to 1990 psi, the maximum pressure in service being 850 psi and fairly steady. Since eleven of the joints had been rejected for radiographic defects, it was concluded that the inspection of the welds was too severe. The circumferential and longitudinal stresses in the pipe were 3600 to 17,800 psi, and 1850 to 9000 psi, respectively. Failure eventually occurred in an unwelded section of one of the pipes.

EAST GERMANY

The November 1960 *Zis-Mitteilungen* of East Germany is concerned with resistance welding. The first paper provides a method of comparing the capacity of resistance welders based on maximum electrode force and secondary current. Another paper describes a device to prevent operation of the welder on inadequate line voltage. A strip filament lamp and photocell are the essential components. Other papers deal with the spot welding of buses and steam radiators.

The December 1960 issue of *Schweisstechnik* (Berlin) contains the following articles:

- Spot welding machines may be modernized by substituting pneumatic for foot pressure, and ignitrons for mechanical switches.
- The design of spherical gas holders 65-ft diam weighing 220 tons is explained. A tilting jig was used to weld the curved shell plates in the shop by the submerged-arc process.
- An automatic fixture for CO_2 welding chain sprockets is described.
- The submerged-arc welding of mild steel conveyor rollers is described.
- Rimmed steel plates were used satisfactorily for submerged arc welded tanks and boilers, but a 2% Mn wire was necessary.
- In 1959 the East German shipyards produced 58,000 sq ft of welds computed from length and thickness of weld. Of this total 10% was produced by submerged arc and CO_2 welding. A broad program was in effect in 1960 to increase the proportion of automatic welding.

FRANCE

Soudage et Techniques Connexes, November-December 1960, contains the following articles:

The all-steel Commerce Bridge in Liege, Belgium, is a continuous steel girder 560 ft long on supports 410 ft apart. The bridge is partly riveted, partly welded. Most of the steel was low-alloy Ac52 with an elastic limit of 51,000 psi and a design stress of 37,000 psi. Carbon and manganese were 0.20% max and 1.50% max, respectively. A Charpy V value of 20 ft-lb at −4° F was required. Since the heat-affected zone did not exceed 350 Vickers hardness and the maximum thickness was 1 in., no preheat was required as shown by the Reeve test. The steel was not embrittled by strain aging. Low-hydrogen electrodes were used. The steel was made by the basic bessemer process and, except for one or two heats, was not normalized.

ITALY

The ultrasonic inspection of circumferential welds in high-pressure steel pipe $2^1/_2$- to 8-in. diam, $^3/_8$- to $^3/_4$-in. wall is described in the Italian welding magazine (Issue No. 4, 1960). 75% of the defects detected ultrasonically were found by radiography also. The remaining 25% consisted of small cracks that were not visible on radiographs.

POLAND

The August 1960 issue of the *Polish Welding Review* describes the remelting of submerged-arc slag to produce a satisfactory flux for welding at the Danzig shipyard. The slag is cleaned, ground, melted in an electric furnace, granulated in water, dried, screened and subjected to magnetic separation. This product exhibited easier slag removal in a root bead in a butt joint than flux fused from 70% new flux and 30% slag.

SWEDEN

The November 1960 issue of *Svetsen*, the Swedish Welding Society's publication, contains an account of a visit by Swedish engineers to eleven Japanese shipyards. Emphasis is on shipyard layout and organization rather than on welding. Even in the mild climate of Japan, preheat is commonly applied.

USSR

Avtomaticheskaya Svarka for October 1960 contained the following articles:

- Welding is being applied widely in the Chinese People's Republic. Research is under the Technoscientific Machine Institute in Pekin. The welding division is in Harbin and at the beginning of 1960 had 192 employees, 22 engineers, 16 technicians. There are three laboratory divisions—electroslag,

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UNITED KINGDOM

Welding the underside of a transformer tank.
(Courtesy Robert Jenkins & Co., Ltd.)

weld deposition and gas-shielded process—as well as a design bureau, experimental shops and service laboratories. Covered electrodes are made locally to standard Russian formulas in shops that usually are parts of factories for other purposes. The Pinchen electrode factory in Shanghai and the electrode factory in Mudan are the largest. Submerged arc welding flux is made in the large boiler and other factories, such as the Dalnin locomotive works and Harbin boiler works. Standard Russian formulas and wires are used. There is still no central mill for wire. Electroslag welding is used in 25 plants for boilers; presses and massive welding equipment are manufactured in plants in Shanghai. The Chinese welding magazine *Khante* (Welding) was started in 1956 at the Harbin Polytechnic Institute, where there is a professorship in welding. The journal has a circulation of 11,000.

- The electrical conductivity of electroslag fluxes was measured up to 2550° F. Extrapolated values at 3630° F ranged from 3 to 15 $Ohm^{-1}CM^{-1}$.

The November 1960 issue of Russia's *Avtomaticheskaya Svarka* contains the following articles:

- The technique of starting and ending submerged arc welds made with three electrodes in tandem is explained. The lead electrode is extinguished first; the middle electrode is extinguished last at the end of a weld.
- A belt to provide flux backing for the inside submerged arc welds of large diameter-shells is described.
- A jig for gas metal-arc welding small diameter steel pipe is described.
- An electrode containing 0.08% carbon with Cr, Mo and V is recommended for CO_2 welding creep-resistant steels.
- The method of designing a constant-potential welding rectifier is explained.
- The design of an electric soldering iron for impulse soldering is described.
- A portable flash welder for rail joints is described having a capacity of 120 KVA at 50% duty cycle. Flash welding was 30% cheaper than a bolted joint.

WEST GERMANY

The West German *Schweissen und Schneiden* for November 1960 contains the following articles:

- A classification of welding processes is offered.
- The manifolding of acetylene cylinders and the piping of acetylene is described.
- Several types of steel plate were CO_2 welded with electrodes containing 1.5% Mn, 1.0% Si. Killed steel containing 0.2% Si was welded with less spatter than semikilled steel containing 0.04% Si. Properties were satisfactory, but the impact value at room temperature and −4° F was very low after strain aging.
- Butt welds made with the oxyacetylene torch in rails have been satisfactory both on the surface and in coal mines. The upper third of the rail is welded with a rod producing weld metal with 250 Brinell.
- The German system for designing welded parts for machinery and trucks subject to fatigue is explained. Safety factors in bending fatigue range from 0.2 for a single fillet to 0.9 for a completely-penetrated fillet on both sides or a butt with reverse-welded root.
- German standard DIN1732 for aluminum and aluminum alloy filler metal has been issued. Eleven compositions are listed, including four purities of aluminum, four Al-Mg alloy, and two Al-Si alloys (5 and 12% Si). Dimensions are specified, but not mechanical properties.

Schweissen und Schneiden, December 1960, contains the following articles:

The Thyssen works of Phoenix-Rheinrohr in Dusseldorf has installed the following new equipment: 7500 ton bending press for pressure vessel plates, 31 MeV Betatron, Pilger mill for seamless tubing 3 to 7 in. diam, Yoder-type mill for roller resistance welding of the longitudinal seams of pipe $6^5/_8$- to $16^1/_2$-in. diam, $^1/_8$- to $^3/_8$-in. wall. Annual capacity of the resistance welding mill is 150,000 tons.

Open-webbed beams are made from rolled-I beams by cutting the web with an automatic oxygen cutting torch along a zig-zag line, and welding the two parts together. According to the November 1960 issue of *Acier*, a German firm cuts three beams at a time with one workman. Tests showed that the moment of inertia of the beams was 10% greater than estimated by Stein's formula.

Repair Welding

The October 1960 issue has 20 brief articles on repair welding. The use of a consumable contact tube for filling deep holes by electroslag welding is described. For repairs in spheroidal graphitic cast iron, a magnesium-treated rod is used for both gas and tungsten-arc welding, the latter process being 50% faster than the former.

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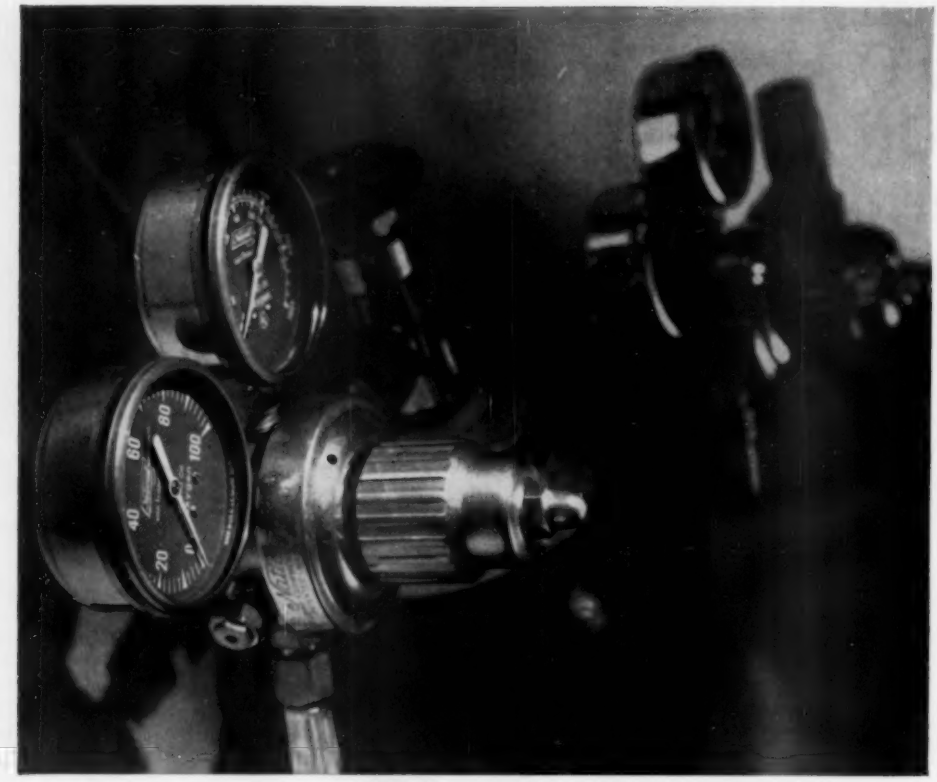

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The Untapped Potential...

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There is, however, another area of development whose potential has not yet been fully recognized by industry—the area of maintenance and repair welding. While developments in this field have been every bit as spectacular as those in production welding—industry has been slow to apply them. Management seemed content to replace rather than repair. It required the harsh economic events of the past 15 years, however, to change this concept. Faced with the serious challenge of earning a profit despite higher taxes, rising costs and increased foreign competition, American industry found it could no longer afford the high cost of the replacement doctrine. Modern machinery had become too complex . . . too interdependent . . . and too expensive . . . to be hastily discarded.

As a result, management began to recognize the wisdom of the "repair rather than replace" concept. They discovered that this approach not only had the obvious effect of cutting down capital expenditure, it reduced expensive spare parts inventories as well. More important, because repairs could be speedily executed "in position," it drastically cut the downtime involved in dismantling equipment, waiting for the replacement, and final re-assembling.

As the economic value of the "repair concept" gained recognition, there was a marked increase in the activity and number of in-plant maintenance welding operations. New techniques and materials were developed to make maintenance and repair welding easier and more economical. Hundreds of new specialized products were placed on the market, making it possible to execute salvage operations once considered impossible.

Yet, despite the progress made in this area, it is surprising to find that the maintenance welder is still regarded by many as a "necessary evil" rather than as a significant source of profit. This attitude stems from the fact that management has not yet become sufficiently aware of the full potential of the maintenance welder. It is up to us—the entire welding industry—to make this potential known and understood.

At a time when there is deep concern for America's ability to compete industrially with other nations of the world—we cannot allow this important "weapon against waste" to remain unused. The fulfillment of this goal will in no way cause us to detour from the goals of our individual companies, for the course most beneficial to our nation's economy is the same course that can benefit us all.

Leonard C. Barr
PRESIDENT
EUTECTIC WELDING ALLOYS CORP.

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PICTURE
OF A WELDOR
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HARNISCHFEGER
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Pipe girth-welding in the field using automatic CO_2-shielded consumable-electrode welding machine

An Automatic Process for Welding **Girth Joints** in Steel Pipelines

is used in a fixed horizontal position and is characterized by excellent weld quality, high welding speeds and elimination of weld backing rings

BY J. W. NELSON, G. E. FAULKNER, P. J. RIEPPEL AND H. C. COOK

SUMMARY. An automatic arc-welding process for welding girth joints in steel pipe in a fixed horizontal position was developed at Battelle Memorial Institute under the sponsorship of the Esso Research and Engineering Company. The process has many desirable features. Weld quality is excellent. Welding speeds are high, up to 55 ipm, so that present pipeline construction rates can be matched or exceeded. Single-pass welds are made in pipes with wall thicknesses of $5^1/_{16}$ in. or less. Weld backing rings are not required. The process is readily adaptable to all pipe diameters. Manpower requirements are low. The conditions that cause underbead cracking, which sometimes is a problem with present pipeline welding methods, are eliminated.

In general, the automatic process is a method for adapting CO_2-shielded consumable-electrode arc welding to pipe girth-welding operations. This welding method was selected after detailed studies and evaluations of other arc-welding processes, flash welding, gas pressure welding, and induction pressure welding. Good weld quality and fast welding speeds are readily achieved with the CO_2-shielded process. However, it was necessary to develop conditions to produce a narrow weld that had a small

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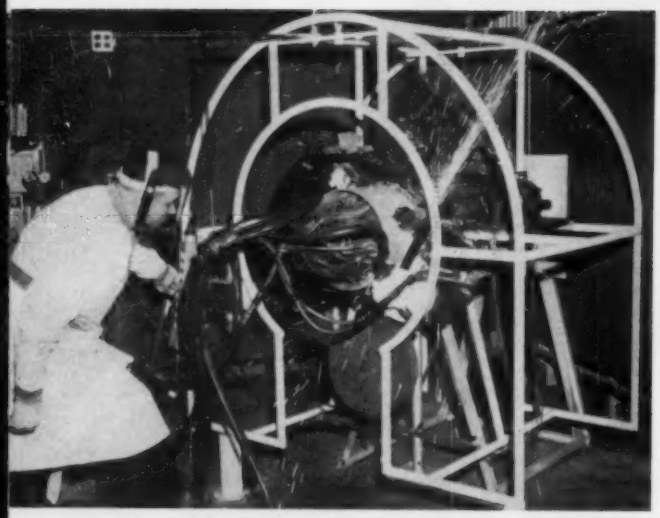

Fig. 1—Laboratory welding apparatus showing joint-preparation operation used with the automatic welding process

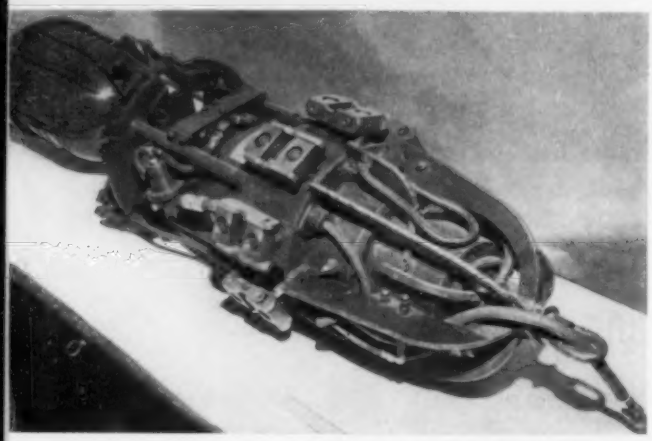

Fig. 2—Automatic pneumatic clamp fitted with pivoting knurled clamping shoes for use with process

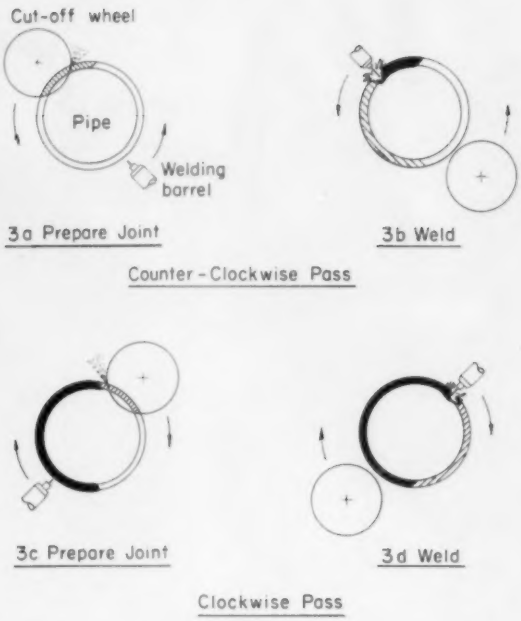

Fig. 3—Sequence of operation for welding fixed-position small-diameter pipe

molten zone and fast cooling rate to make possible welding in all positions around a fixed pipe. The success of the process is achieved through accurate control of joint dimensions and welding conditions. The accuracy is obtained by using novel techniques and the latest equipment advances.

Equipment has been constructed for welding 4- to 8-in. diam and 16-in. diam pipe with the process. A satisfactory field test has been made with the small-diameter pipe welding unit. The 16-in. diam pipe welding equipment will be field tested in the near future, and equipment is being made for welding 30- to 36-in. pipe.

Background

Pipeline owners and fabricators have long been aware of the potential advantages of an automatic process for girth-welding steel pipe in the field. They have wanted such a process to increase pipe-laying rates, to reduce the distance between welding and ditching operations, to become less dependent on the manual dexterity needed for manual welding, and to improve the over-all economy of pipeline construction. Fully-automatic field welding of pipelines was done several years ago by a major natural gas company. This welding was done by gas pressure welding. Several hundreds of miles of pipelines were made by this process, but it was eventually abandoned because good-quality welds were not produced consistently.

Gas pressure welding, induction pressure welding and flash welding were given serious consideration at the outset of this program to develop automatic pipe welding. These processes were not pursued far because of equipment size and cost. Also, gas tungsten-arc welding and low-penetrating, intermittent-arcing, consumable-electrode welding processes were not selected because welding speeds were low.

The gas metal-arc welding of aluminum pipe has been used successfully for some time, but an automatic arc-welding process for welding steel pipe has not been available until now. The welding of aluminum pipe was developed first, because it is easier to weld aluminum in all positions than steel. The chief problem in past attempts to arc weld steel pipe automatically was to keep the molten steel from flowing out of the weld joint in the vertical and overhead positions. This problem was much more serious with steel than with aluminum, because the aluminum solidified at a much higher rate as a result of lower melting point and high thermal conductivity.

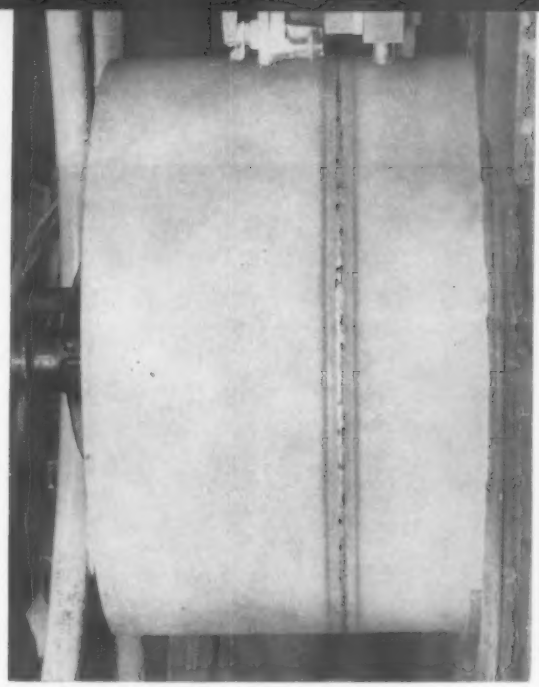

Fig. 4—Completed girth weld in 16-in. wall T-52 pipe. (Dark discolorations are thin manganese-silicate flakes on the weld surface)

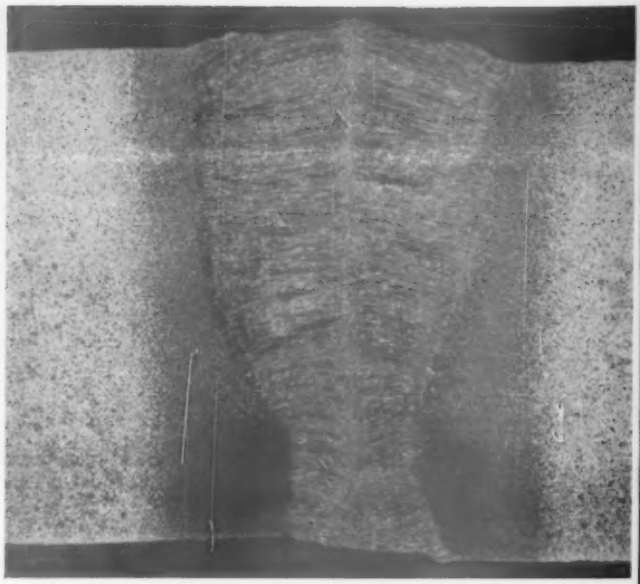

Fig. 5—Macrograph of typical single-pass weld made in 0.280-in. wall pipe. Nital etch. × 10

A CO_2-shielded consumable-electrode arc-welding process for steel pipe was developed after long and detailed studies of joint geometry, welding equipment, welding power supplies, welding speeds, backing materials, and all of the parameters that are involved in this type of welding in all positions from downhand to directly overhead. The CO_2-shielded arc-welding process developed in this program makes high-quality welds in pipeline steels at high rates without backing bars. The equipment costs are relatively low, and the welding equipment is light and portable.

Process Description

Three major operations are performed in making girth welds with the automatic pipe-welding process:*

1. The pipes are aligned for welding.
2. The joint is prepared for welding.
3. The weld is made.

Special equipment is used to prepare the joint and make the welds. The laboratory apparatus used for this purpose is shown in Fig. 1.

Conventional internally expanding alignment clamps are used to hold the pipes in position for welding. Such a clamp is shown in Fig. 2. The clamp is fitted with clamping shoes that bridge the joint to hold the pipes rigidly aligned. The clamping shoes are pivoted so that the clamp can be expanded into one pipe while the other pipe is lined up. When the second pipe is in position, the clamp is then expanded into the second pipe. The clamping shoes have knurled surfaces to facilitate rigid clamping.

Except for end preparation and joint spacing, the pipes are aligned by conventional procedures. The ends of pipe with wall thicknesses of $^5/_{16}$ in. or less are prepared with square ends for the automatic process rather than the beveled ends used for manual welding. Also, the pipe ends are spaced so that they are almost touching for automatic welding rather than having the usual root spacing that is necessary for manual welding.

After the pipes are aligned, the pipe-welding machine is lined up with the joint and the automatic process is started. The sequence of the automatic process for making welds in pipe 16 in. or less in diameter is shown schematically in Fig. 3. First, the joint on one side of the pipe is prepared for welding from top to bottom. The joint is prepared by cutting a narrow space between the pipe ends with an abrasive cutoff wheel. The cutoff wheel is mounted on the pipe-welding machine. After one-half of the joint is prepared, it is welded in the downhill direction from the top to bottom of the pipe. A conventional gas metal-arc welding head is mounted on the machine to make the weld. Next, the other side of the joint is prepared. Then, the second side is welded, again in the downhill direction. When the second side is completed, the line-up clamp is removed and line-up of the next joint started. Both the joint preparation and welding operations are carried out at speeds of up to 55 linear ipm. Thus, a complete weld can be made in 16-in. diam, $^5/_{16}$-in. wall pipe in slightly more than 2 min without an overlap of operation. A typical girth weld is shown in Fig. 4.

* Apparatus and process patents have been widely applied for. Licenses have been arranged whereby Air Reduction Sales Co. can manufacture the apparatus and Crutcher-Rolfs-Cummings, Inc., and H. C. Bauer Associates can handle its distribution to pipeline interests. It is expected that this new technique will therefore be made available to industry in the most efficient manner.

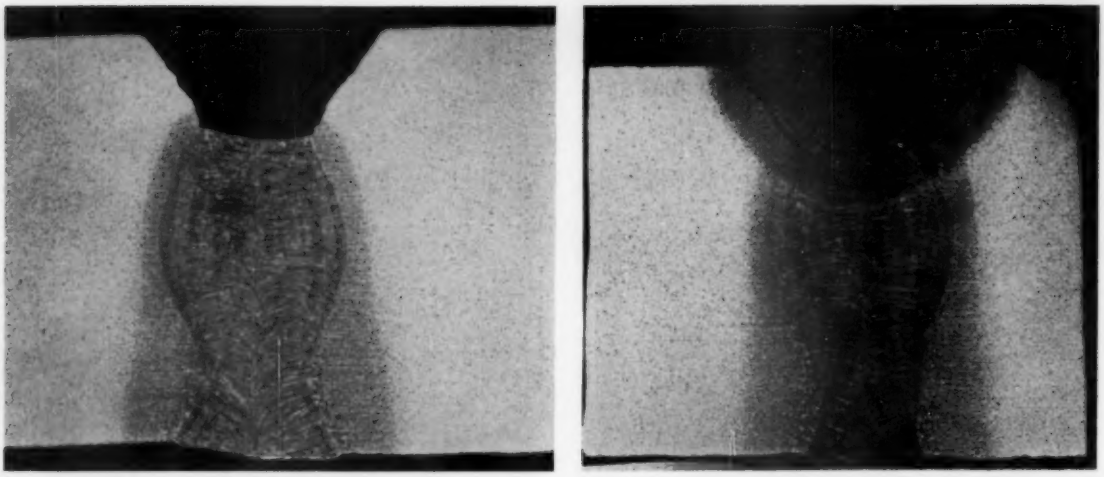

Fig. 6—Weld in heavier wall pipe

(a) Macrograph of first pass. × 6

(b) Macrograph of complete 2-pass weld. × 6

Another sequence is required for large-diameter pipes—for example, 30-in. diam. In order to finish the welds in this size of pipe in 2 min, it is necessary to prepare the joint and weld simultaneously with one or multiple cutting and welding units. Welding times as low as 1 to $1^1/_2$ min. can be anticipated with some automatic sequences.

Although the mechanics of the process appear simple, several novel features are incorporated into the process to make it work. One of these features is the geometry of the weld. Other features are the methods used to control welding conditions.

Weld Geometry

Weld geometry is one of the most important features of the process, because it represents an optimum relationship between the amount of molten weld metal deposited in the joint and the arc forces that control the flow of this metal. Weld geometry, in turn, depends on the dimensions of the prepared joint and the welding conditions that are used. All of these are carefully controlled in the automatic process.

Cross sections of typical girth welds that are obtained with the process are shown in Figs. 5 and 6. Figure 5 shows a cross section of a single-pass weld made in pipe with a nominal wall thickness of 0.280 in. This weld is made with a square butt joint with a root spacing of about $^1/_{16}$ in. Single-pass welds are made in pipes with wall thicknesses of $^5/_{16}$ in. or less. Figure 6 shows the cross sections of two-pass welds in $^3/_8$-in. wall pipe. The joint dimensions of the two-pass weld are designed so that the root pass simulates the square-butt joint used with the single-pass weld.

The joint geometry features of the automatic process are characterized by the single-pass weld shown in Fig. 5 and the root pass of the weld shown in Fig. 6. These welds are very narrow and have depth-to-width ratios of about 2. This narrow weld results from the square-butt type of joint, high welding speeds and other welding conditions that are used. There is only a small amount of molten metal in these welds at any time. This small amount of molten metal and the high cooling rates that are obtained make it possible to produce the weld in all positions around a pipe.

The CO_2-shielded process is readily adapted to welding square butt joints in pipe. The deep penetrating arc of the CO_2-shielded process easily pene-

Table 1—Welding Conditions for Use with the Automatic Pipe-Welding Process

Pipe wall thickness, in.	$^9/_{32}$	$^3/_8$	
Joint design	Square butt	60-deg bevel, $^1/_{16}$-in. root pass	
Gap width, in.	$^1/_{16}$	$^1/_{16}$	
		Two	
Number of passes	One	Root	Face
Welding wire (highly deoxidized) diameter, in.	0.040	0.040	0.040
Voltage	CPRP	CPRP	CPRP[a]
Arc voltage	27–28	27–28[b]	20
Amperage	300	380	210
Travel speed, ipm	44	55	30
Wire feed rate, ipm	560	650	250
Head angle (wire leading head), deg	12	12	12
Shielding gas	CO_2	CO_2	CO_2/argon
Gas flow rate, cfh	30	30	40/10
Costs for wire and gas (per ft of weld)	3¢	6¢	6¢

[a] With welding reactor in series with generator.
[b] 29.0 v required at start.

trates and fuses the root of such joints without forming a wide bead. Actually, arcing occurs at about the center of the weld. The superheated molten weld metal flows under the arc to the root and behind the arc to the face of the weld where it melts the upper and lower corners of the joint, thereby resulting in uniform fusion into the base metal without excessive weld reinforcement.

The weld is made in the downhill direction. By welding in this direction, the molten weld metal flows into the arc due to gravitational forces. The arc forces, however, control the flow of the weld metal so that it does not flow out of the joint or under the arc in sufficient amounts to raise the arc out of the joint and decrease weld penetration to an unsatisfactory condition.

As mentioned previously, the weld geometry represents an optimum relationship between the amount of molten metal in the joint and the arc forces that control the flow of this metal. This relationship is so well controlled in the automatic process that consistent root fusion and small weld reinforcement, which are important characteristics of the process, are obtained without the use of a weld backup.

Process Variables and Controls

The process has many variables that are accurately controlled to ensure consistent weld quality. These variables are listed in Table 1. Included also are the conditions used to weld pipes with nominal wall thicknesses of $^{9}/_{32}$ and $^{3}/_{8}$ in.

Joint Dimensions

The joint-preparation operation that is incorporated into the process is used to control root spacing. Accurate control over root spacing is needed to obtain the weld geometry that is required for the single-pass welds and the root pass in multiple-pass welds. Many methods were considered for achieving accurate root spacing, but the method selected is to align and clamp the pipes in preparation for welding and then cut a space between the ends of the pipe with an abrasive cutoff wheel. This method of preparing the joint is extremely accurate, and root spacing is controlled by selecting cutoff wheels of the proper width.

The abrasive cutoff wheels that are used with the process were selected to provide fast cutting rates without the use of a coolant. The cutoff wheels are commercially available in the thicknesses required for the process. The rotational speeds of the wheels are set to minimize wheel breakage without sacrificing cutting speed. The joints are prepared at linear speeds up to 55 ipm. Approximately 200 linear in. of joint are prepared with one wheel.

The use of the cutoff wheel to control root spacing in the joint also serves another important function. All welding with the automatic process is done in the downhill direction. Therefore, the weld is made starting at the top and going down one side of the pipe to stop at the bottom. Then, the weld is started again at the top and made down the other side of the pipe to stop a second time at the bottom. By preparing the second side of the joint after the first side is welded, the curvature of the cutoff wheel allows the ends of the first weld to be tapered (Fig. 7), thereby promoting excellent weld quality in the area where the ends of the welds overlap.

The joint-preparation operation produces joints with precise root spacings. The welding clamp is important in maintaining the spacing. During welding, contraction of the weld results in forces that tend to pull the edges of the joint together. Therefore, a clamp that resists these forces is required. Satisfactory clamping is achieved with the commercial clamp shown previously.

Welding Conditions

The joint-preparation operation provides accurate control over joint dimensions. However, the other welding conditions also are accurately controlled to ensure consistent weld quality. The other welding conditions are controlled as follows:

1. Wire-feed speed and weld travel speed, which affect welding current, heat input and weld penetration, are accurately controlled by tachometer feed-back, thyratron-controlled direct-current motors.

2. Contact tube-to-work distance, which affects weld penetration, is kept constant by means of a roller that rides the pipe surface, as shown in Fig. 8.

3. Alignment of the welding wire in the center of

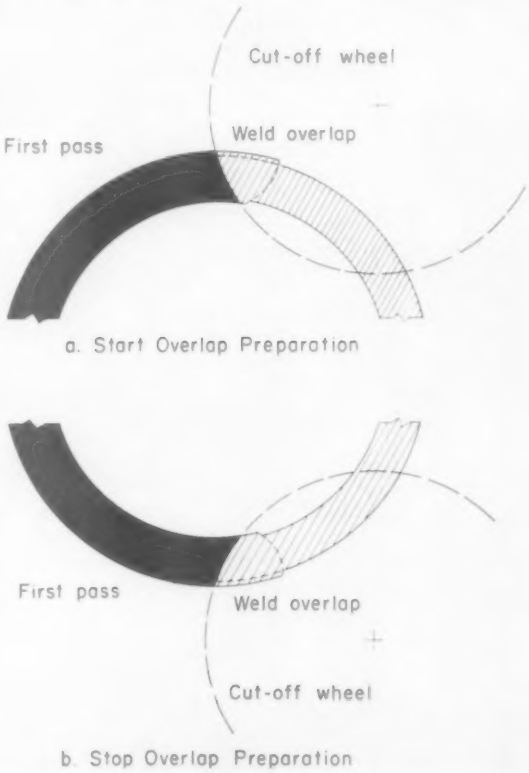

Fig. 7—Weld overlap preparation

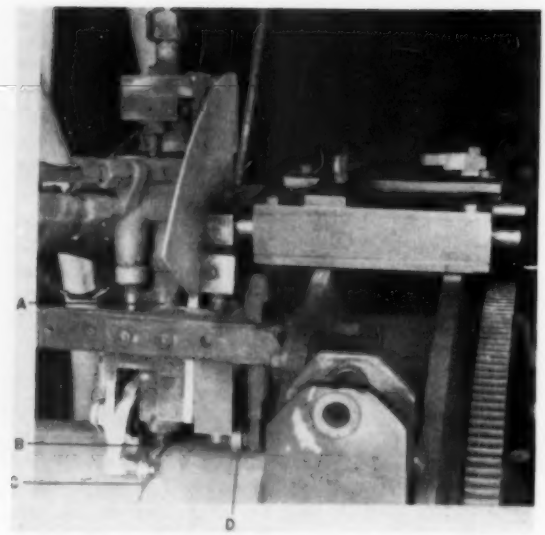

Fig. 8—Welding assembly

(a) Welding barrel
(b) Welding wire
(c) Groove follower in weld joint
(d) Height adjustment wheel to control contact tube-to-work distance

the weld joint is maintained with the groove-following device shown in Fig. 8. This is necessary, since wire alignment also affects weld penetration.

4. The proper angle of the welding head is determined by fixed stops on the mounting bracket for the welding head barrel.

Arc voltage is important because it affects the width of the weld, which in turn affects weld penetration. An automatic device for controlling arc voltage and manual control of arc voltage is used with the process. The characteristics of the welding power source affect arc voltage and weld consistency. A constant-potential, direct-current welding power source is used.

Filler-wire diameter and composition are important. A commercial highly-deoxidized filler wire with a diameter of 0.040 in. is used. The highly deoxidized wire is required to minimize any tendency to form porosity in the welds.

Process Equipment Requirements

The success of the automatic process is achieved through accurate control of joint dimensions and welding conditions. The need for these accurate controls imposes important requirements on the equipment that is built for the process.

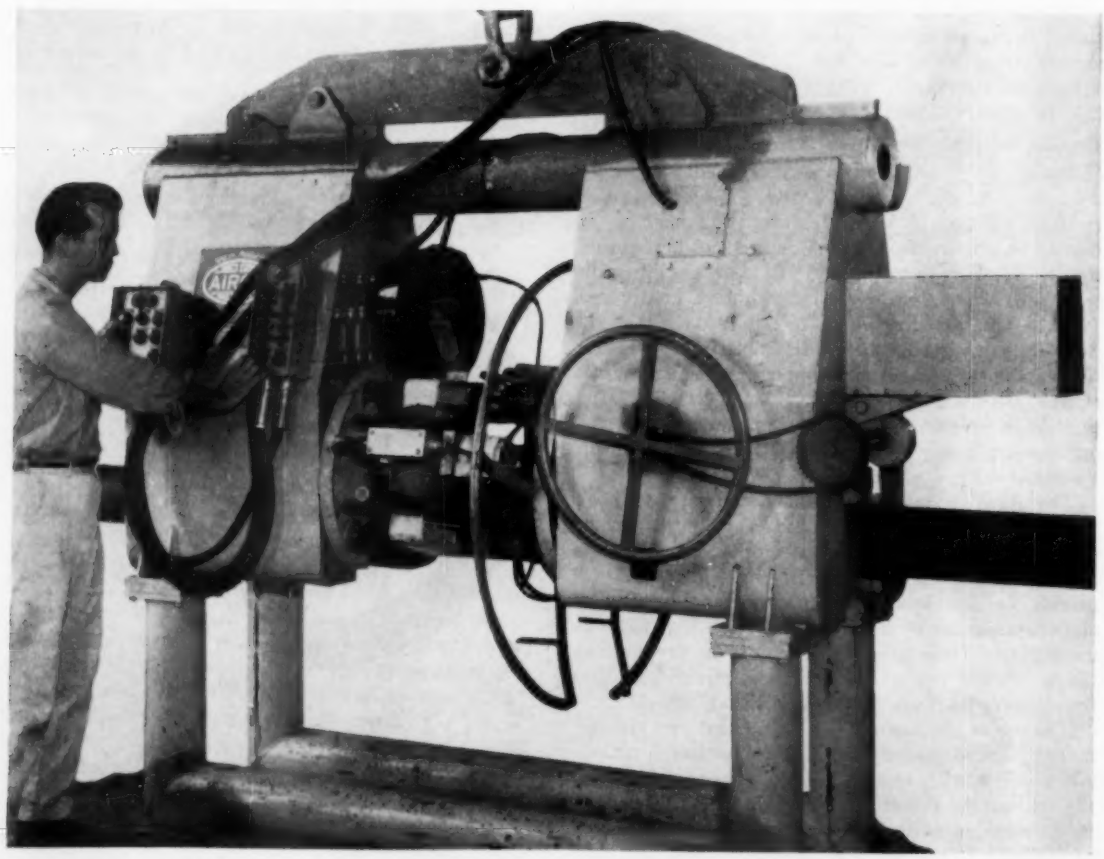

Fig. 9—Field welding apparatus for welding small-diameter pipe

Fig. 10—Cutting unit on small-diameter pipe-welding apparatus

Fig. 11—Welding unit on small-diameter pipe-welding apparatus

A prototype machine built for welding 4- to 8-in. diam pipe is shown in Fig. 9. This machine was used to "field test" the process in the oil field of Odessa, Tex.

The most obvious function of the pipe-welding machine is to rotate the joint preparation and welding units around the pipe. The equipment now available is best described as a rotating ring-type unit. With this equipment, the joint preparation and welding units are attached to a split ring that is rotated around the pipe. The split ring is supported through bearings by the frame of the machine which is clamped to the pipe. The ring is designed to allow the units to be lifted from the pipe.

Several important requirements are imposed on the rotating equipment by the joint-preparation operation: (1) the equipment must be rigid and rotate the sizing unit in a single plane, (2) the plane of the cutoff wheel and plane of rotation of the equipment must coincide, (3) the plane of the joint must be lined up with the cutoff wheel and plane of rotation, and (4) the sizing operation must be started and stopped at certain locations. All of these requirements are necessary to ensure successful joint preparation. The requirements imposed by the welding operation are: (1) the rotation speed must be accurate, and (2) the welding operation must be started and stopped at certain locations.

The joint preparation and welding units are attached to the rotating ring. Included in the joint-preparation unit are an electric or air motor to rotate the cutoff wheel, an electric motor, hydraulic unit or pneumatic unit to feed the cutoff wheel into or away from the pipe, and microswitches to control the distance that the cutoff wheel is fed into the pipe. The joint-preparation unit on the 4- to 8-in. pipe welding equipment is shown in Fig. 10. Included in the welding unit are a welding nozzle mounted on a floating bracket equipped with a groove following mechanism and a unit which controls contact tube-to-work distance, a constant-speed wire-drive system which includes a clutch to allow the wire-feed motor to reach speed before wire is fed, a pneumatic or hydraulic system for changing head angle, and a mechanism for moving the welding head into position for welding and retracting it. The welding unit on the 4- to 8-in. pipe welding equipment is shown in Fig. 11.

In welding 16-in. diam and smaller pipe, joint preparation and welding are not done at the same time. Equipment for welding such pipe is made

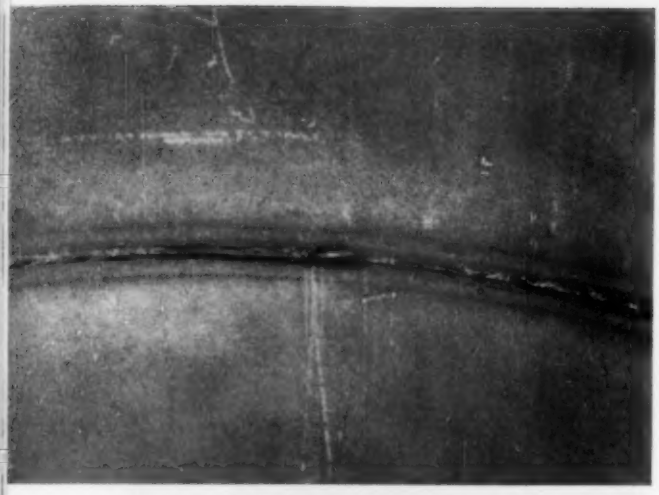

Fig. 12—Root of weld made in 16 in. diam by $^3/_8$-in. wall pipe. (Start overlap at center of weld. Dark discolorations are thin manganese-silicate flakes on the weld surface)

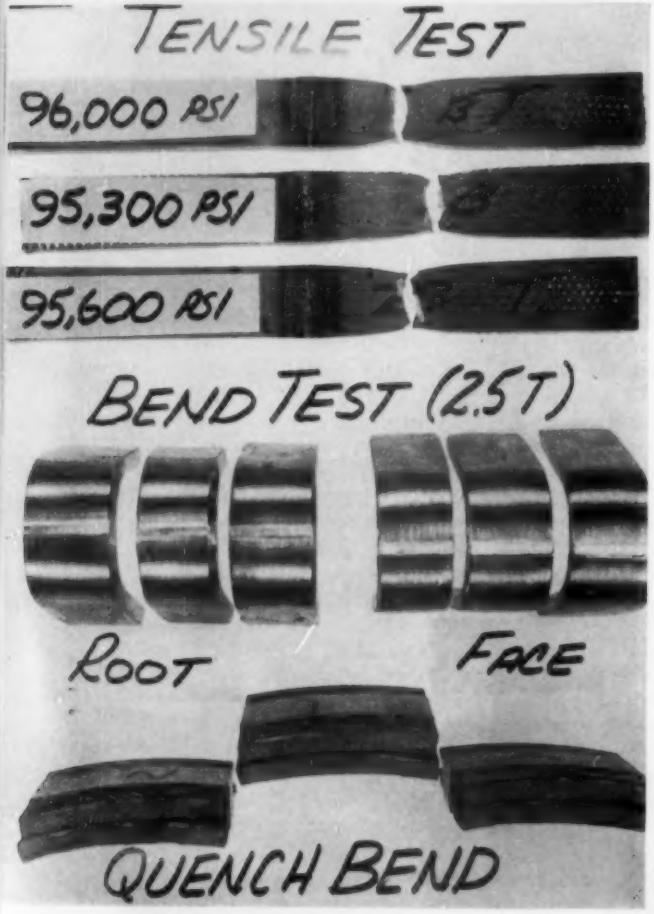

Fig. 13—Typical mechanical tests. 16 in. diam by $^1/_{16}$-in. wall pipe

with the welding and joint-preparation units placed 180 degrees apart on the rotating mechanism. With this arrangement, the welding unit is in position to start welding when the joint is prepared and vice versa. The welding machine is equipped with microswitches and a control circuit to obtain the proper sequence of operations and to ensure that cutting and welding start and stop at the proper positions around the pipe.

Weld Quality

Visually, welds made with the automatic process differ in contour from manual welds. The face of a single-pass weld was shown in Fig. 4. The faces of these welds are very narrow and are essentially flat with no reinforcement on the top quadrant of the pipe. The faces of two-pass welds in $^3/_8$-in. wall pipe are about twice as wide as the single-pass weld with uniform weld reinforcement in all positions around the pipe.

The roots of single- and multipass welds are similar in appearance to the roots of manual welds, except that the reinforcement is slightly lower in the vertical welding position and uniformity is much better than for manual welds. A typical weld root is shown in Fig. 12.

The mechanical properties of welds made with the automatic process are satisfactory and meet the usual requirements for pipeline welding. Tensile test specimens fail in the base metal with and without weld reinforcement. Most bend specimens are successfully bent around a radius of less than two times their thickness, even welds in pipe having yield strengths over 52,000 psi. Normally, welds in such pipe are considered satisfactory by code requirements, if they can be bent around radii of 4 times their thickness. In addition, nick-break specimens, which are intentionally notched in the weld to direct the failure to that point, do not fail in the weld-metal zone. A special bend test in which the specimens are quenched from temperatures above the upper critical temperature is required to cause failure in the weld metal. Typical tensile and bend specimens are shown in Fig. 13.

Sound welds that readily pass radiographic specifications also are obtained. The use of improper filler wire, however, will result in excessive porosity.

Acknowledgment

The authors wish to express their appreciation for the technical assistance offered by Messrs. M. J. Dabney and M. F. Sheely, of Esso Research and Engineering Co. Acknowledgment also is due F. A. DeSaw, of Battelle, who assisted in the development of the welding process in many ways. Furthermore, the assistance of the Air Reduction Co. in making available Figs. 9, 10, and 11 is gratefully acknowledged.

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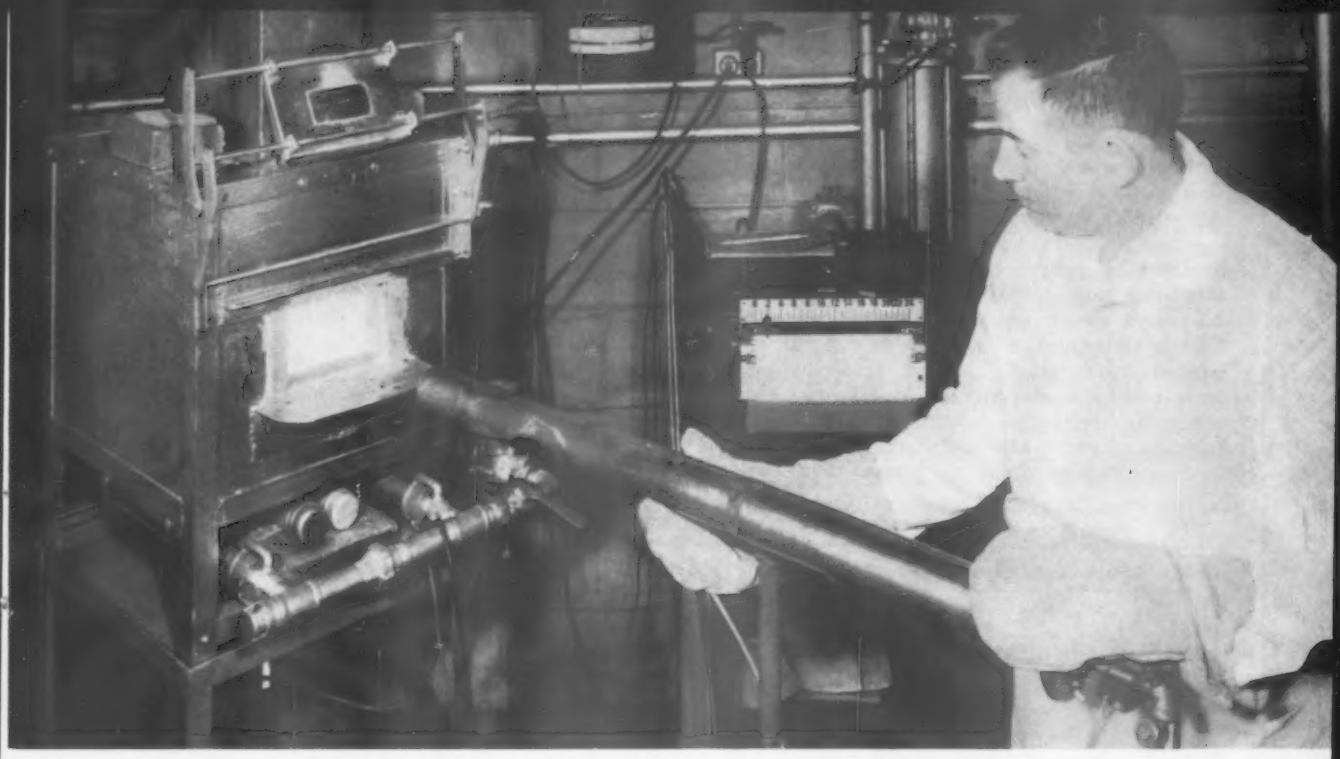

Braze tests of T-specimens are performed under controlled conditions in this small research laboratory furnace. Specimens are placed in tube-type hydrogen retort; brazing operation duplicates production operation, but on smaller scale

Importance of Purity in Manufacturing Brazing **Filler Metals** for High Temperature Service Applications

is best demonstrated by brazing tests in that joint strength is not directly related to the melting method used

BY FORBES M. MILLER

The brazing of stainless steel or high alloy components for high temperature service applications is most frequently accomplished with nickel-chromium base brazing filler metals. Other commonly used brazing alloys have a nickel-phosphorous or nickel-manganese base. Precious metal brazing alloys are also used, but to a considerable lesser extent with the result that discussion here is limited to the more widely accepted and used nickel base materials.

Nickel-chromium base filler metals have boron, silicon, phosphorous and other constituents added as required for specific uses. The first of these alloys was introduced in 1948 and has been used

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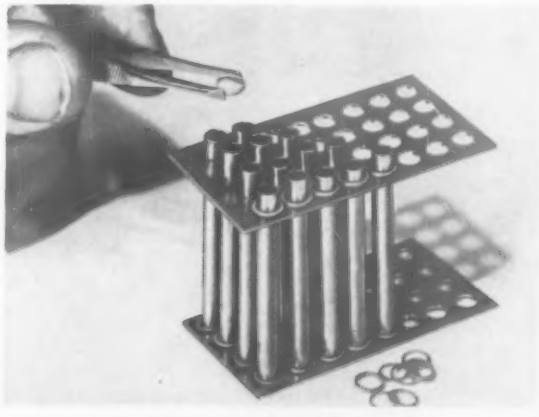
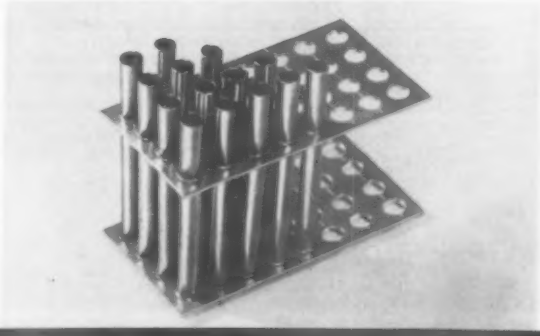
Fig. 1—Use of nickel-chromium base brazing filler metal in prefabricated ring shape cut assembly time 85% in this stainless steel tube assembly





for high temperature service brazing since that time. This material is now known as AMS 4775 and is indisputably the standard of the industry.

A typical group of filler metals for high temperature service applications is listed in Table 1. This tabulation lists composition and general properties. All alloys shown are available in powder form. Certain alloys also are available as cast rod, plastic bonded sheet, plastic bonded wire, flux-powder paste and/or special prefabricated forms (Fig. 1).

Specific application recommendations and comparative physical and metallurgical properties of the same brazing alloys are presented in Table 2.

Brazing Alloy Purity

Any alloy which is to be used for brazing high temperature metals (like stainless steels) must be of a very high purity. "Purity" in a brazing alloy means primarily freedom from refractory oxides (titanium, aluminum, or silicon oxides), although any oxidized metal or certain dissolved gases, such as oxygen or nitrogen, are undesirable in brazing alloys.

Metal oxides and oxygen or nitrogen inclusions may affect brazing alloy flow and thereby impair brazability. Dissolved hydrogen, on the other hand, is not harmful in a brazing alloy because it is

Table 1—Composition and Properties of Typical Brazing Filler Metals for High Temperature Service Applications

Alloy No.	Nominal composition, Ni, Bal., %	Solidus temp., °F nominal[a]	Liquidus temp., °F nominal[a]	Recommended atmosphere[b]	Typical joint tensile shear strength, psi[c] AISI 470 base metal, Rc 38-40	AISI 304 base metal, Rb 72	Joint corrosion resist. in NaK and high temp water[d]	Microconstituents of alloy, before brazing[a]	Ductility of joint[e]
AMS 4775	Cr 13.5, Fe 4.5 B 3.5, C 0.8 Si 4.5	1790	1900	A, B	56,100	48,000	Proved satisfactory	Peritectic and solid solution	Excellent over 720 deg
AMS 4776	Cr 13.5, Fe 4.5 B 3.5, C 0.15 max Si 4.5	1780	1970	A, B	57,140	60,700	Satisfactory	Peritectic and solid solution	Excellent, over 720 deg
AMS 4777	Cr 6.5, Fe 2.5 B 3.0, C 0.15 max Si 4.5	1780	1830	A, B	56,100	37,200	Proved satisfactory	All peritectic	Excellent up to 720 deg
Wide gap alloy	Cr 11.5, Fe 3.5 B 3.0, C 0.15 max. Si 3.5	1780	2000	A, B	...	...	Satisfactory	Peritectic and solid solution	Dependent on joint clearanc
Alloy 10	P 11.0 C 0.15 max.	1610	1610	A, B, C, D	...	27,600	Not known	95 to 100% eutectic	Fair, 270 deg
Alloy 30	Cr 19.0 Si 10.0 C 0.15 max.	1975	2075	A, B, C	98,300	59,300	Proved satisfactory	Peritectic and solid solution	Excellent, up to 720 deg
Alloy 50	Cr 13.0 P 10.0 C 0.15 max.	1630	1630	A, B, C	...	31,400	Proved satisfactory	95 to 100% eutectic	Good, 540 deg
Alloy 60	M 17.0 Si 8.0 C 0.15 max.	1850	1890	A, B, C	69,510	34,400	Not known	95 to 100% eutectic	Excellent, up to 720 deg
AMS 4778	B 3.0 Si 4.5 C 0.15 max.	1800	1900	A, B	57,500	33,900	Proved satisfactory	Peritectic and solid solution	Excellent, up to 720 deg
Alloy 150	Cr 15.0 B 3.5 C 0.15 max.	1930	1930	A, B	80,000	34,400	Satisfactory	95 to 100% eutectic	Excellent, over 720 deg
Alloy 160	Cr 10.0, Fe. 2.5 B 2.0, C 0.45 max. Si 2.5	1780	2120	A, B	...	...	Satisfactory	Peritectic and solid solution	Excellent, over 720 deg
Alloy 170	Cr 11.5, Fe 3.75 B 2.5, W 16.0 Si 3.25, C 0.55	1790	2020	A, B	...	...	Satisfactory	Peritectic and solid solution	Excellent, over 720 deg

[a] Data taken from Wall Colmonoy laboratory cooling curves.

[b] Recommended atmospheres for brazing alloys (stainless steels and high chromium base metal require class A, B, or C). A. Pure dry hydrogen or inert gases. B. Vacuum. C. Dissociated ammonia (—60° F dew point or better). D. Exothermic; rich, unpurified 6:1 air to gas ratio, or purified and dried.

[c] Data taken from laboratory tests using the Miller-Pealsee shear test specimen for brazed joints.

[d] Data compiled from reports of tests conducted by AEC laboratories and by private industry manufacturers of nuclear reactors. Tests were conducted on brazed joints of Type 304, 310 stainless steel and Inconel base metals.

[e] The ductility was determined by twisting a brazed, Type 304, S.S. "T" specimen, 5 in. long with legs 0.032 by 0.375 in. (Fig. 7).

released during the brazing operation.

Manufacturing Practice

In the manufacture of high temperature service brazing alloys, several factors must be considered:

1. Melting must be done in a pure atmosphere, such as pure dry inert gas or very low pressure vacuum.

2. Special melting furnace refractories must be used which will resist attack by some of the very reactive metals (silicon, boron, phosphorous) used as constituents in the brazing alloy.

3. High purity raw materials must be used; refining should not be performed during the process of melting high temperature brazing alloys—it is better to use high purity raw materials.

4. Pouring of the alloy after melting must be done in such a manner as to prevent the metal from becoming oxidized.

5. Powdering of the alloy also must avoid oxidation of the metal.

It is significant to note that protection from potential oxidation must be provided in every manufacturing step. It is not enough to provide a protective atmosphere for the melting step alone. If some protective atmosphere is not maintained and the metal is poured in water or open air, the metal will become oxidized. This means that

Table 2—Selector Chart for Typical Brazing Filler Metals for High Temperature Service Applications[a]

	Brazing filler metals containing B (no P)								Si (no B)		P (no B)	
Application[a]	AMS 4775A	AMS 4766	AMS 4777	Wide gap alloy	AMS 4778	Alloy 150	Alloy 160	Alloy 170	Alloy 30	Alloy 60	Alloy 10	Alloy 50
High temperature, high stress moving engine components	A	A	B	C	B	A	C	A	A	C	C	C
Heavy nonmoving structures (variable gaps)	A	A	A	A	B	A	A	A	B	C	C	C
Honeycomb and other thin materials	C	C	B	C	B	B	C	C	A	A	A	A
Atomic reactor core assemblies	D	D	D	D	D	D	D	D	A	A	B	A
Large machineable or softer fillets	B	B	C	A	C	C	A	B	C	C	C	C
For contact with liquid metals: NaK, mercury	A	A	A	B	A	A	A	A	A	B	C	A
For use with tight or deep joints	C	C	B	C	B	B	C	C	B	A	A	A
For torch brazing when used with special flux	A	A	A	A	A	A	A	A	B	B	B	B
Property												
Joint strength[b]	1	1	1	3	2	1	3	1	1	3	4	2
Solution and diffusion with base metal	1	1	2	1	2	2	3	3	4	4	4	5
Fluidity	3	4	2	5	2	2	4	4	2	1	1	1
Oxidation resistance of joints, °F[c]	1 Up to 2200	2 Up to 2000	3 Up to 1800	3 Up to 1800	3 Up to 1800	3 Up to 1800	4 Up to 1700	1 Up to 2200	2 Up to 2000	4 Up to 1700	6 Up to 1400	5 Up to 1575
Suggested brazing temperature, °F[d]	2150	2150	1900	2100	1900	2150	2175	2150	2175	2050	1800	1800
Brazing range, °F	1950–2200	1975–2200	1850–2150	2100–2200	1850–2150	1950–2200	2100–2200	2100–2200	2100–2200	1900–2100	1700–1850	1800–1950
Recommended joint gaps, range	0.002–0.005	0.002–0.006	0.001–0.004	0.010–0.030	Contact 0.002	0.001–0.004	0.005–0.020	0.004–0.010	0.001–0.004	Contact 0.002	Contact 0.001	Contact 0.001
Corrosion resistance	Corrosion resistance will depend on type of base metal, brazing filler metal and interaction during brazing. Tests are required to determine specific corrosion resistance for a given application											

[a] Recommendations and comparisons are based on information from laboratory tests and plant experience and from commercial and private plant experience. Application reference code: A—best; B—satisfactory; C—least satisfactory; D—contains boron, has high neutron absorption ratio. Comparative property code: from 1 (highest) to 6 (lowest).

[b] Joint strength also depends on brazing cycle, joint design and joint clearance.

[c] Tests on Inconel base metal joints, exposed 400 hr in still air at indicated temperature. No deterioration of fillet. Alloy 170 tests on Hastelloy X.

[d] Exact brazing temperature for any specific joint depends on desired joint and base metal properties desired. It also will depend on different base metal, brazing alloy and joint design combinations. Consequently, it may sometimes be necessary to determine ideal brazing temperature by experiment.

protective measures must be maintained for pouring and powdering operations as well as for melting.

All nickel-chromium brazing alloys are available in powder form. Powdering is accomplished by atomization or fragmentation (ball milling, hammer milling or other mechanical means). Whether a brazing alloy is powdered by atomization or fragmentation is not important, as long as the following conditions are met:

1. The purity of the alloy (freedom from oxygen and nitrogen) is maintained.
2. The particle size is controlled.

Although particle size in a brazing filler metal is not critical, it should be realized that the presence of extremely coarse particles or extremely fine particles could be detrimental to the brazing action by adversely affecting the application and flow properties. Hence it is important that particle size be controlled within reasonable limits.

Most nickel-chromium brazing alloy powders are specified and furnished −150 mesh. However on special applications, some users specify −325 mesh size (particles 325 mesh and down), usually to facilitate application. Normally the finer mesh size does not affect brazability. However, if poor flow should be encountered when using the finer powders, it is usually caused by a marginal atmosphere.

Fig. 2—Jet engine diffuser assembly shown as retort bell is lowered into place prior to brazing. All components are of AISI Type 321 stainless steel—are simultaneously brazed in pure dry hydrogen atmosphere using AMS 4775 brazing filler metal

Vacuum Vs. Inert Gas Melting

One of the most broadly misunderstood facts relating to brazing filler metals is that *brazed joint strength is in no way directly related to the melting method used.* This fact is hard to accept, because it seems to contradict a long-established metallurgical truth with regard to the manufacture of steels or other constructional metals. The effect of melting practice on brazing alloys, however, is not the same as the effect of melting practice on steels.

If constructional metals are produced by vacuum melting, for example, there is a definite relationship between the vacuum melting practice and the final strength of the ingot, bar or rolled sheet. That is not the case with a brazing alloy, since joint

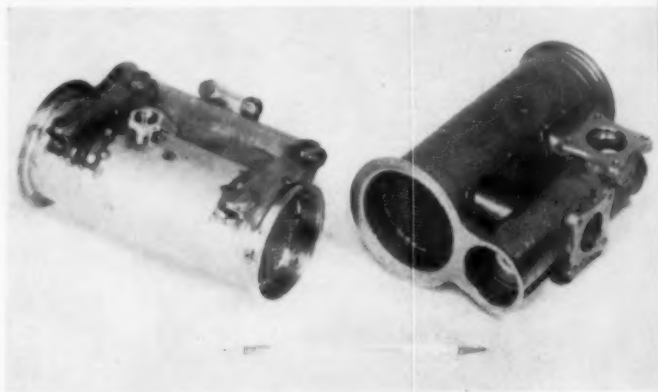


Fig. 3—This stainless steel aircraft heat exchanger is used in the fuel coolant system. It is a unique brazing application in that two different brazing alloys must be used to permit all components to be brazed at one time without sacrificing basic design objectives. Excellent strength in housing-to-external-components joints is achieved with AMS 4775 brazing alloy. The tube bundle or inner core was brazed with Alloy 160. This alloy was chosen to produce joints of greater ductility on the thin wall (0.005 in.) tubes without increasing the danger of erosion.

Fig. 4—Heavy metal sections usually call for filler metals like AMS 4775, AMS 4776, Alloy 150 or Alloy 170. In this jet engine starter combustion chamber assembly, AMS 4775 was used. The 21 parts of 300 Series stainless steel were simultaneously furnace brazed in a pure dry hydrogen atmosphere

strength is dependent upon such factors as joint design, joint gaps, brazing temperature, amount of alloy applied, heating rate and many, many other considerations that go to make up what is termed "brazing technique."

Melting practice only affects the purity of the metal fillers. Purity, in turn, only determines whether or not the filler will braze. A nonbrazable alloy—one that contains a significant percentage of refractory oxides—will not flow properly during the brazing cycle. It will fail to flow where it should or will go only part way through the joint.

Proper flow, on the other hand, is the best means for determining a satisfactory braze. Once a satisfactory braze has been obtained, the strength of that brazed joint will depend upon the brazing and design considerations, not upon how the brazing alloy was produced or even on the composition of the brazing filler metal specifically.

Any oxygen or oxides in the brazing alloy can be harmful in applications involving certain titanium- or aluminum-bearing base metals (such as Inconel X or A286). In such cases, the oxygen or oxides present in the filler metal could, in turn, oxidize the base metal. The aluminum and titanium oxides thus formed cannot be reduced in normal, commercial brazing atmospheres.

Again, however, it is important to emphasize that brazing alloy impurities affect only the brazability or brazing properties of the brazed part. They have no quantitative effect on strength, corrosion resistance or other brazed joint properties. They determine only whether or not a satisfactory braze can be achieved. It is obvious that, if an unsatisfactory braze is produced, none of the joint properties could be satisfactory.

A good vacuum atmosphere is comparable to a good inert atmosphere with regard to producing a pure brazing alloy. Another way of expressing this is to say that a poor vacuum melt would be worse than one performed in a good inert atmosphere. In the same way, a poor inert atmosphere would be worse than a good vacuum melt, all other factors being equal. The quality of the filler metal produced is strictly dependent upon the purity of both the atmosphere and the raw materials used.

In any vacuum operation, there will always be a certain amount of air present, no matter how good the vacuum is. The lower the pressure, of course, the better the atmosphere will be. By the same token, all air cannot be displaced with an inert atmosphere. The purity of the atmosphere is determined by the dew point of the gas—the lower the dew point, the better the atmosphere and, consequently, the purer the brazing alloy produced.

Regardless of the degree of atmosphere purity maintained during melting, it is of no value in producing a high temperature brazing filler metal unless comparable emphasis is placed on furnace linings, pouring practice, raw materials and powdering methods.

Diffusion and Erosion

The degree to which the filler metal penetrates and alloys with the base metal during brazing is referred to as diffusion. In applications requiring strong joints for high temperature, high stress service conditions (such as turbine rotor assemblies and jet engine components—Fig. 2), it is generally good practice to specify a filler metal that has high diffusion and solution properties with the base metal. Where the assembly is constructed of extremely thin base metals (as in honeycomb structures and some heat exchangers), good practice generally calls for a filler metal with a low diffusion characteristic relative to the base metal being used. Diffusion is a normal part of the metallurgical process that can contribute to good brazed joints, when brazing high temperature metals with nickel base filler alloys.

Solution exists to some degree in every brazed joint but is harmful only when the amount is sufficient to cause erosion. The amount of solution of the base metal is affected by such factors as solubility of the brazing alloy in the base metal, the quantity of brazing alloy applied to the joint and the brazing cycle (time and temperature). Erosion (caused by excessive solution) is not affected directly by the manner in which the brazing alloy is manufactured. The filler metal physical properties determining solution, erosion, strength, corrosion resistance, etc., are inherent chemical characteristics, which are not changed by melting practice or even by the purity of the brazing alloy.

The amount of impurities in the brazing alloy will not change its basic solubility in a given base metal. Should a very impure filler metal be used, however, there probably would be no erosion, because there would be no braze. The refractory oxides in the brazing alloy would prevent satisfactory flow. When there is no braze, there can be no erosion.

Probably the most important factor affecting degree of erosion for a given filler-base metal combination is the brazing technique, which encompasses assembly and fixturing practices, alloy application and the brazing cycle, itself.

As an example, the amount of brazing alloy applied to the joint is very critical on honeycomb material, which may include base metal sections as fragile as 0.001-in. thick, and in many heat exchangers where base metal thicknesses are 0.003 to 0.005-in. and where there are many thousands of inches of brazed joints (Fig. 3). If the quantity of filler metal is as much as 0.002-in. thick, it could penetrate all the way through the brazed joint. It might even completely dissolve the base metal. Erosion can be controlled if the right filler metal is selected for the job, if its application is properly controlled, and if other phases of brazing technique are correct.

Airframe manufacturers, for example, are brazing AISI 304 stainless steel and Inconel X honeycomb structures, using nickel-chromium-phosphorous,

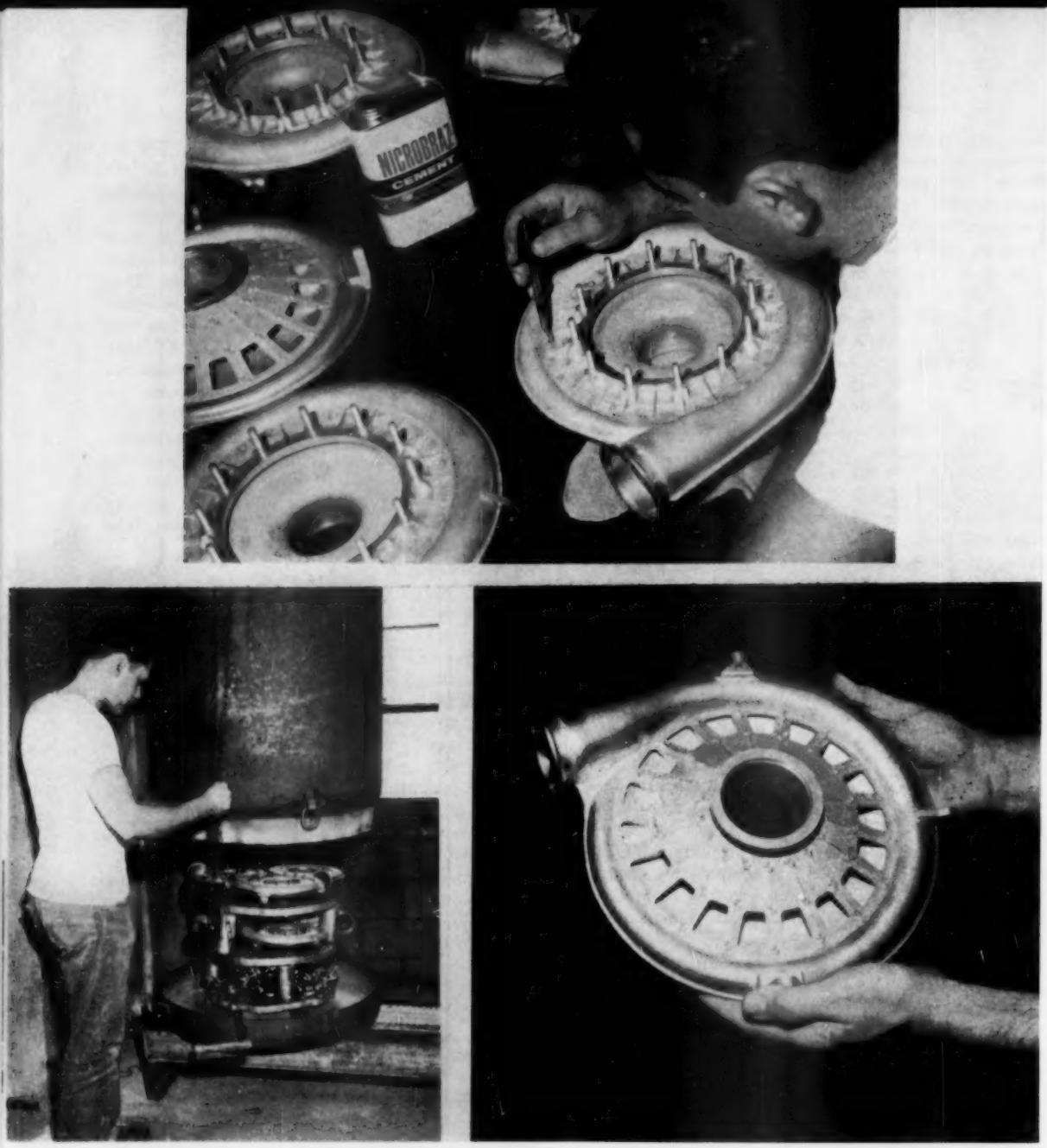


Fig. 5—Special skill is required for brazing alloy application. Here powdered alloy, mixed with a cement binder, is being applied with a glass dropper to a stainless steel compressor turbine assembly

nickel-chromium-silicon and nickel-silicon-manganese brazing alloys. The brazing technique permits very quick heating with correspondingly short time requirements (reported to be from two to five minutes). The filler metals in these applications provide the necessary high temperature resistance and strength, while the fast heating rate eliminates the dangers of erosion despite the extremely thin honeycomb sections. With the proper atmosphere and extremely fast heating rate, fluxes or corrosive getters like lithium are not required. Results produced in this manner with the nickel-chromium filler metals cannot be achieved with silver base brazing alloys, either with or without lithium.

On heavier section thicknesses, the brazing alloy quantity applied is usually controlled (for good brazing practice) to produce penetration of around 2% of base metal thickness (Fig. 4). In such an application, erosion can be said to be nonexistent.

As previously indicated, special skill is required for brazing alloy applications. Such skill is especially important in controlling erosion. Equally important as the quantity of alloy is exactly how it is placed in relation to the joint. In some applica-

tions it is placed near the joint and allowed to flow in; in others it is placed on the joint and allowed to flow through; in still others it is placed right in the joint and allowed to flow in several directions. Each job is a different problem of alloy placement which must be figured out.

Determination of alloy placement and quantity is mostly an art. There is some science to it, but in the powder form especially it is still very much an art (Fig. 5). No simple quantitative formulas can be used to determine the amount of alloy to use in a given application.

In the case of a brand new design, it is usually necessary to make a few trial runs to check out brazing technique. It is possible to draw heavily on past experience with parts of like construction or similar design. However the happy accomplishment of determination of the right combination of the many, many brazing technique factors on the first try is seldom the case. The people with the most experience in brazing for high temperature service applications are, of course, most capable of coming up with the right answers with the least wasted effort. That is why new designs are so frequently assigned to qualified job shop type operations; experience has shown that this is generally the best way to save time and money.

Testing

Brazing alloys produced for high temperature service must be tested by some means to insure the quality of results achieved during melting and powdering operations. Chemical analysis is not sufficient to detect impurities, especially refractory oxides and oxygen, hydrogen and nitrogen gas inclusions.

Unfortunately, there are presently no industry standards for making the needed tests. Since the real test of brazing alloy quality is the production of a satisfactory braze, Wall Colmonoy conducts special brazing tests under carefully controlled laboratory conditions of every lot brazing alloy produced. T specimens 5-in. long are brazed under precise conditions using a brazing cycle similar to that used in production operations with regard to temperature, time and atmosphere (lead photograph).

A precisely measured quantity of brazing alloy is applied at one end of the specimen. It must show complete flow along the entire length on both sides with uniform fillets on both sides. The joint is examined for any minute defects that might affect its brazability.

Any nonuniform flow or evidence of joint defects signifies an unsatisfactory alloy and that lot is rejected. Oxidation resistance and twist tests (Fig. 6) are also performed to prescribed standards to ensure adequate mechanical properties in the brazed joint (Table 1).

The possible presence of oxides of titanium, aluminum or calcium, even in minute quantities, is potentially harmful in a brazing alloy. A chemical analysis to determine the presence of such impurities is impractical, however, for two important reasons: First, it is impossible to determine from a quantitative chemical analysis whether or not the compound is present in sufficient quantity to affect filler metal brazability. Second, it is so much quicker, simpler, less expensive and more positive to run an actual brazing test.

The brazing check is an absolute indication of whether impurities are extensive enough to affect brazability. Without a braze test, the presence or absence of anything else in the brazing alloy is of no consequence. Without brazability there is no joint. Without a joint there can be no strength or corrosion resistance or anything else.

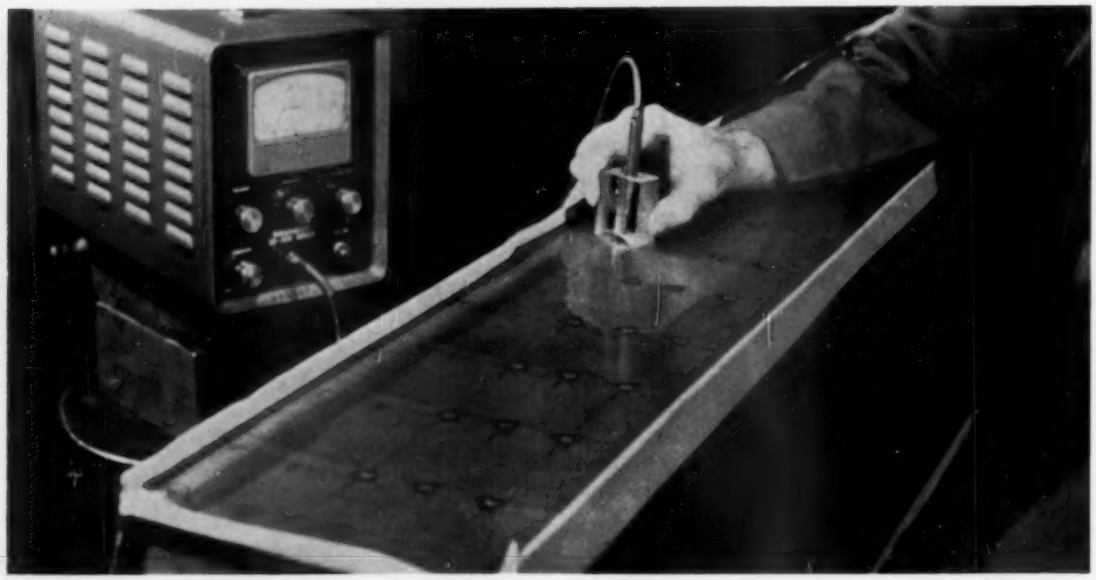
This brings the issue back once again to the importance of melting practice in production of a brazing alloy. Brazability is the only thing that is affected by melting practice and technique. Good brazability can be achieved equally well by melting in either vacuum or inert gas atmospheres, if all phases of the filler metal manufacturing process are suitably controlled.

Fig. 6—Twist test of brazed T-specimen determines ductility of joint as reported in Table 1 properties

Spot welds with fit-up gaps exceeding 0.005 in. between sheets are shown to be feasible in the

Semi-automatic Gas Tungsten-Arc **Spot Welding** of Stainless Steels and High Temperature Alloys

BY R. J. CAMPBELL AND D. R. MILLER



Eddy current instrument used to measure sheet separation prior to welding

Introduction

The Aircraft Nuclear Propulsion Department of the General Electric Co. was actively engaged in a research and development program to produce a nuclear power plant for aircraft application. Development of this power plant required the use of high-strength to weight ratio welded sheet metal structures fabricated from high temperature alloys such as 19 - 9DL and Type 316 stainless steels, Inconel, Inconel X, Hastelloy X and René 41. The type of joining process selected to manufacture these nuclear components is generally dependent upon the contour of the part, type of material, combination of material thicknesses and weld joint location.

The engineering designs on several of these assemblies have lap weld joints requiring the use of resistance spot welding. A major limitation of resistance welding on a portion of the lap welds was inaccessibility for electrodes. The design contained several with multiple thickness joints, and it was questionable whether proper resistance welding techniques could be developed for producing spot weld nuggets free of defects. Since final designs had been frozen, it was mandatory that a joining process be employed that provided engineering weld strength requirements by welding from one side only.

The most economical and practical welding process available for welding from one side only was considered to be the gas tungsten-arc spot-welding process. Early attempts to apply this process to the joining of high temperature alloys, using commercially available welding equipment without filler wire addition to the weld puddle, met with little success. Apart from a general inconsistency in appearance and strength, the arc spot welds in

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these high temperature alloys exhibited a marked tendency to crater cracking. This was attributed to the common hot cracking phenomena associated with high temperature alloys (Fig. 1).

It was the opinion of the authors that the hot cracking problem could be rectified if a welding machine could be designed to incorporate precision control of weld time, weld current slope (up and down) and the addition of cold filler wire into the weld puddle. Specifications were written for equipment of this type, and units were purchased from a welding equipment manufacturer who had made and tested a welding power supply design with the necessary requisites.

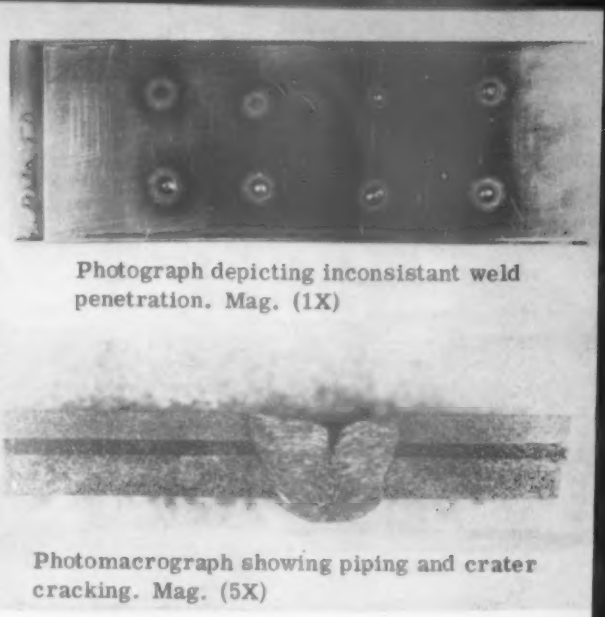
In order to determine the capabilities and versatility of the welding equipment using this new precision on control concept of weld parameters, a welding development program was initiated on several high temperature alloys with various combinations of thicknesses. This report describes the metallurgical and mechanical results of these weldability studies.

The character of some of the welding schedule variables such as electrode size, type of shielding atmosphere, preparation of weld interface surfaces, weld current control and amount of filler wire added to the weld puddle were found to have profound effects on weld performance. A discussion of these characteristics is included to permit a better understanding of their influence.

The procedures utilized for making arc spot welds in multiple ply thicknesses are defined. A method of measuring air gap clearances (Fit-up purposes) between two lapped sheets is also described.

Since the face-side of a weld deposit made by this process is slightly convex and therefore affects air flow, a method of removing the excess material is described.

Although the equipment was designed for gas tungsten-arc spot welding of sheet materials, other uses are described which have proved to be quite useful in manufacturing complicated assemblies.



Photograph depicting inconsistant weld penetration. Mag. (1X)

Photomacrograph showing piping and crater cracking. Mag. (5X)

Fig. 1—Inconsistent weld penetration and crater cracking in arc spot welds made on 19-9DL sheet material without addition of filler wire

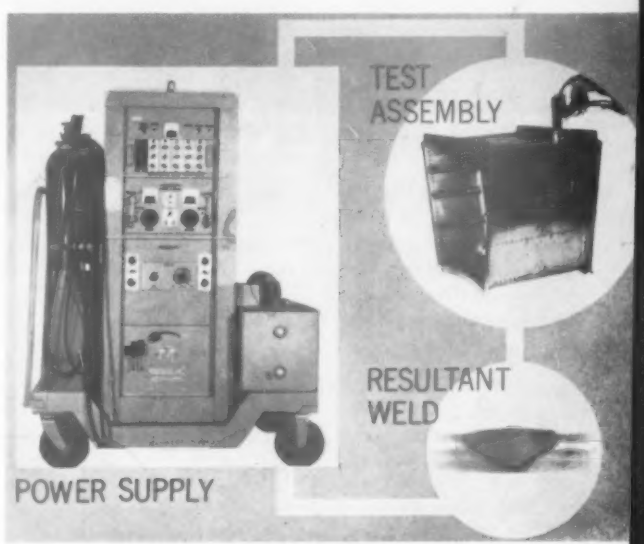


Fig. 2—Gas tungsten-arc spot-welding equipment and typical resultant weld cross section (reduced about 50% on reproduction)

Process and Its Advantages

Gas tungsten-arc spot welding is a joining process where a weld is produced by applying the heat of an electric arc to the top surfaces of two or more lapped pieces of metal (Fig. 2). The welding action is controlled by the current input to the arc, and the time the arc is allowed to dwell. The arc, tungsten electrode, and fluid puddle are shielded with an inert atmosphere in a manner similar to that employed in the conventional gas-shielded arc-welding process.

There are several features of the process that make it attractive as a manufacturing tool:

1. Simple jigging—access to the lap weld is required on one side only.

2. Portability—the equipment is mobile, thus facilitating welding on jigged or complicated structures difficult to handle.

3. Semiskilled operation—the process is semi-automatic and requires only occasional changing and resetting of the tungsten electrode.

4. Strength—the weld shear values obtained compare favorably with those made to resistance welding.

5. Shunting—the center to center distance of spot welds is not limited as in resistance welding, because shunting is not encountered.

6. Multiple thicknesses—it is possible to make welds on multiple thickness joints.

Welding Equipment

The welding apparatus used for the gas tungsten-arc spot-welding development work to be described

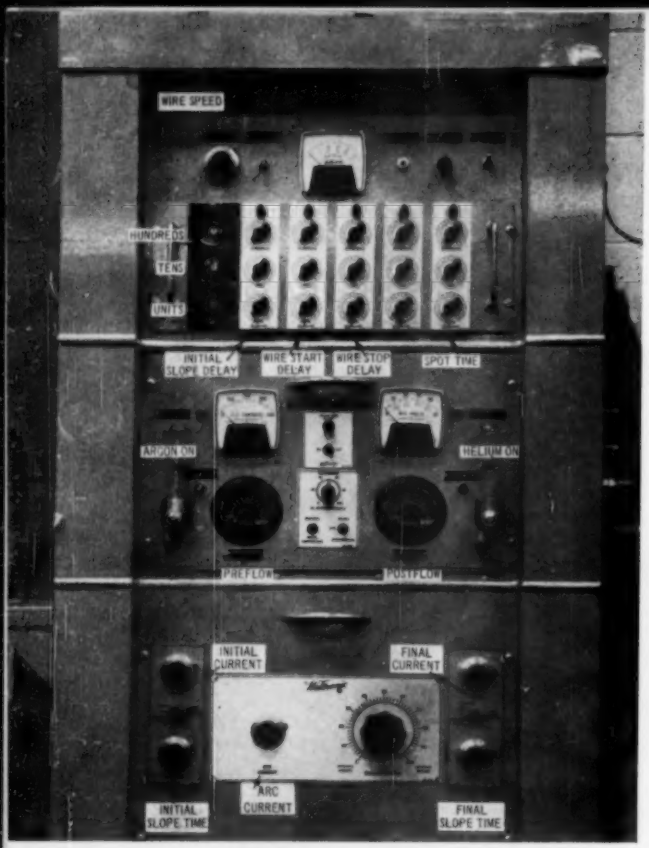


Fig. 3—Welding control panel

is shown in Fig. 2 with a close-up view of the welding control panel in Fig. 3.

The arc current power supply consists of an air-cooled silicon diode rectifier with one welding range from 3 amp at 10 v to 300 amp at 40 v. The power supply is designed for three-phase a-c input with connections arranged for magnetic amplifier reactors. The supply transformer primary is three-phase Delta connected for 220 or 440 v input and has three-phase secondaries at 65 v for Delta connection. Transformer output is connected to the rectifier through the six magnetic amplifier self-saturating reactors which control the current to the rectifier.

Ten turn heli-pot control dials are used for presetting welding current slopes and various welding heat levels. They are an integral part of the high performance amplifier used to drive the magnetic amplifier. The magnetic amplifier is controlled by an inductive feed back signal, which controls the welding current and voltage to $\pm 5\%$ for line voltage variations of $\pm 10\%$.

There are two separate flowmeters for controlling the type of shielding gas to be delivered to the welding gun. Each flowmeter has a separate on-off switch, thus enabling quick transfer to another type of inert gas if required for a specific welding operation. The preflow timer ensures that inert gas is surrounding the electrode before the arc is struck. After the welding cycle has been completed, inert gas continues to flow as controlled by the post-flow timer until the electrode and work have cooled to a temperature at which they will not oxidize.

The spot-welding gun is equipped with collets for tungsten electrode diameters from 0.030 to 0.125 in. The wire feed mechanism for supplying filler wire (0.035 in. diam.) to the weld puddle is an integral and precision part of the welding gun. The wire feed is of a reciprocating nature, i.e., a predetermined increment of wire (as selected by the wire feed control dial) feeds into the molten weld puddle, withdraws completely, and resets—automatically ready for the next weld; all observations are synchronous with the weld cycle time.

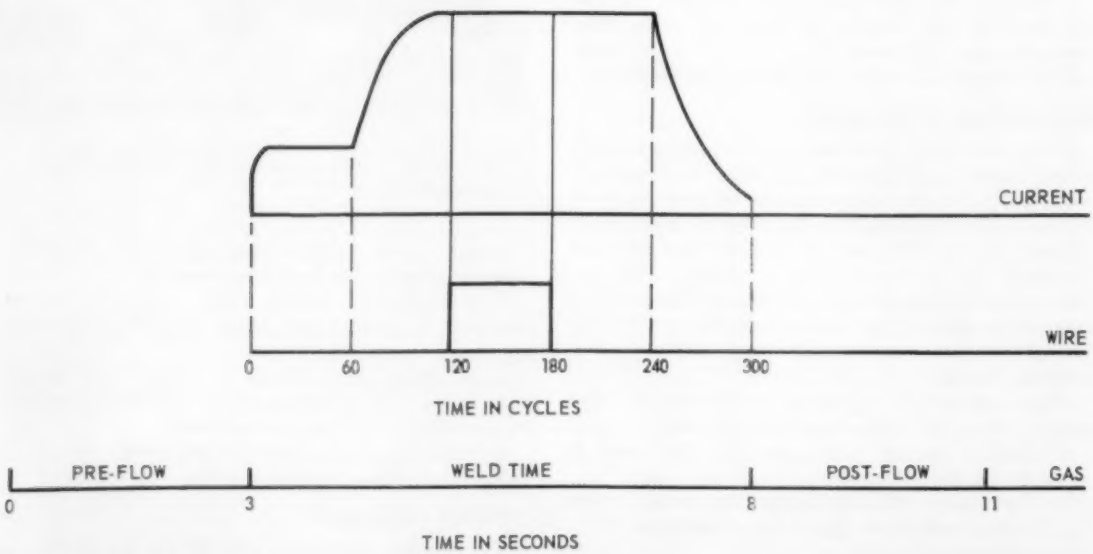


Fig. 4—Typical welding schedule

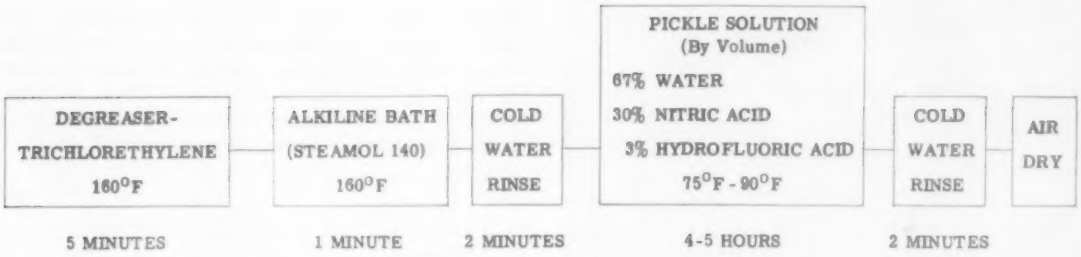


Fig. 5—Cleaning schedule for high temperature alloys

The wire drive control is a standard electronic tube amplifier using a tachometer generator for a motor speed feedback signal, which is compared with a regulated reference voltage. The error difference between the two is amplified and used to control a dual-triode power tube which meters the power to the d-c wire drive motor armature. The motor field is a permanent magnet, and protective circuits are included in the relay sequencing to protect the field. Armature relays provide both forward and reverse operation of the motor in conjunction with a resistor provide dynamic braking of the motor.

The weld time of a spot weld is controlled by a sequence timer consisting of three electronic pulse counting tubes (units, tens, hundreds) with a maximum range of 999 cycles (16.66 sec). The welding time cycle is divided into five steps as follows:

1. Start of initial weld current delay.
2. Start of the wire feed.
3. Stop of the wire feed and retracting the wire.
4. Start of the final weld current slope.
5. Dropping out of the weld primary contactor at the end of the final spot time.

These five steps are independently adjustable for any setting up to 999 cycles and run concurrently rather than in sequence. To obtain a sequence of 60 cycles for each function, initial slope delay would be set at 60, wire start delay at 120, wire stop delay at 180, final slope delay at 240 and spot time at 300 cycles. This would allow initial current to run for 60 cycles and then allow another 60 cycles for initial slope to occur before the wire started. The wire would run for 60 cycles and there would be 120 cycles for the arc current value to run. Final slope would occur in the difference between final slope delay and spot time: 60 cycles. The graphic representation of this welding cycle with the preflow and post-flow inert gas timers preset at 3 sec is depicted in Fig. 4.

Procedure Development Program

Since the process would ultimately be employed to manufacture nuclear components made of high temperature alloys, it was decided that initial development work for both the two-ply and multiple thickness joints should be on materials of the high temperature classification such as 19 – 9DL, Type 316 stainless steel, Inconel, Inconel "X," Hastelloy X and René 41. The thickness combinations selected were taken directly from engineering drawings in which the designer had selected this joining process for fabrication of nuclear assemblies.

Surface Preparation

To obtain consistent welds of high quality, scrupulous attention to cleanliness must be emphasized. Irregularity of heat flow across the interface of two lapped sheets is accentuated by the presence of oxide layers on the surface of the material. These oxides may be present due to prior heat treatments or long storage periods. Previous work on arc spot welding had shown that the presence of these oxides causes variations in depth of weld penetration and in the size of the weld faying plane.

The oxide on these high temperature materials is difficult, if not impossible, to remove by rubbing with steel wool, revolving stainless steel wire brush or rubbing with emery cloth. Grinding is not recommended because it causes variations in material thicknesses at the location of the arc spot welds, resulting in inconsistant weld nuggets. The ideal and more practical method of removing these oxides is by chemical cleaning with a solution and schedule as depicted in Fig. 5. René 41 material requires a vergo salt bath cleaning process.

Electrode Configuration and Arc Length

The next major factor in the production of consistent welds relates to the form of the electrode end and arc length setting. The satisfactory behavior of tungsten inert-gas welding arcs is controlled by electrode composition and configuration is such that a sharp electro-static voltage gradient is established at the tip of the electrode. This gradient can be obtained by pointing the electrode, since it confines resistance heating to the tip and sharply limits the possibility of arc oscillation associated with blunt tungsten electrodes.

The ohmic resistance of a 0.010-in diam tungsten electrode is many times greater than the resistance of a 0.125-in. diam electrode. When the same welding current is passed through each electrode, the smaller diameter electrode is resistance heated to emission temperatures for a considerable part of

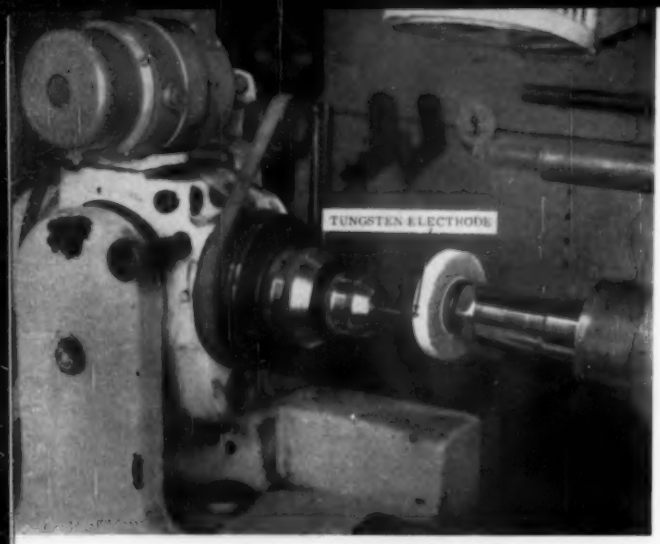


Fig. 6—Precision grinding of tungsten electrode configuration

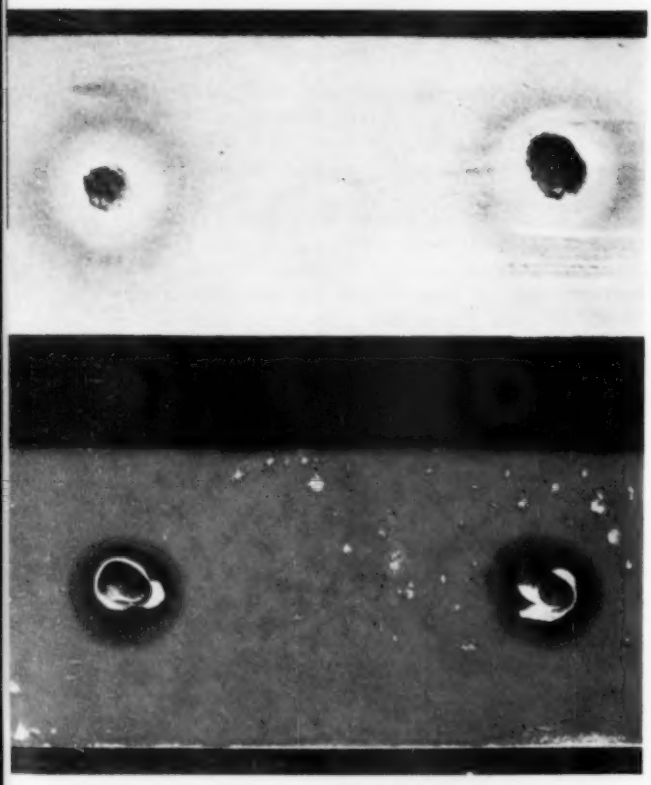


Fig. 7—Ceramic used as a backup material on 0.060 to 0.060 in. Hastelloy X

its length, whereas heating of the larger electrode is confined to its tip. With fine diameter electrodes, the arc is found to climb up the electrode intermittently due to availability of spots which momentarily have lower emission energy requirements. While arc starting is not greatly affected as long as a sharp tip is maintained, arc stability is not assured when fine diameter electrodes are used.

A 0.125-in. diam tungsten electrode containing a nominal 2% thoria was used throughout this investigation. The degree of taper produced on an electrode will govern, to some extent, the amount of erosion that will take place. Three different electrode preparations were evaluated in a series of tests designed to indicate the most suitable shape:

1. Tapered to a point over a length equal to two diameters.
2. Tapered to a point over a length equal to three diameters.
3. Tapered to a point over a length equal to five diameters.

Accurate symmetry and point angles were obtained using precision grinding equipment shown in Fig. 6.

The effect of arc length on the shear strength of arc spot welds has been described by Hackman, Steer and Copleston.[1, 2, 4] As indicated by these authors, shear strength is increased with increasing arc length until a maximum is reached, after which further increases in arc length will cause a decrease in shear strength. Obviously then, selection of the proper arc length for a given application is extremely important. However, as stated previously, the welding gun used in this investigation supplied cold filler wire to the weld puddle during the welding cycle. The design of the guide tube for feeding this filler wire into the weld puddle restricted the arc length to 0.125 in. Therefore, the arc length for evaluating the tungsten configurations and the weld tests to be described were restricted to the above stated arc length dimension.

A maximum current of 200 amp was used with the 0.125 in. arc length to determine the effects of electrode configuration vs. electrode erosion. Results indicated that after 100 starts and stops, there was less erosion on the two diameter tapered electrode; it was, therefore, adapted as the final tip geometry.

Shielding Gas

A series of weld tests were conducted to determine the shielding gas effects of 100% helium, 100% argon and 75% helium - 25% argon mixture on the weld nugget contour and the surface appearance of the weld. It was found that 100% argon produced sound welds in the 19 – 9DL and Type 316 stainless steel materials (the two ply combination) as long as the top sheet did not exceed 0.060 in. thickness. When thickness combinations greater than this were tried, it necessitated the use of the 75% helium – 25% argon mixture. This gas mixture was also required on both the two-ply and multiple thickness joint combination on Inconel, Inconel X, Hastelloy X and René 41 materials. Gas flows of 8–10 cfh were found to be sufficient to prevent the formation of an oxide film over the surface of the weld.

Backing

Although backing the weld may appear to detract from the "one side" feature of the process, it enables higher currents and longer times to be used, thus leading to an increase in shear strength. Backing

also facilitates control of penetration and of surface appearance on both sides. Without a gas backup the under bead would have the typical oxide film or "coke" appearance. A backing atmosphere of 100% argon was used throughout this investigation.

A small amount of development work was done with ceramic backup coatings in place of the inert gas atmosphere (Fig. 7). Initial results appear promising, but additional development work is required to determine the metallurgical effects, if any, of the ceramic on the weld nugget.

Welding Schedules

It is appreciated that the shear strength of any given condition and gage of material will depend on the cross-sectional area of the fused zone at the interface position. Thus far, the process parameters discussed and defined have been of a secondary influence as far as quality and consistency of welds is concerned.

To establish the effect of the three primary variables—current, weld time and filler wire addition—in this process, preliminary tests were conducted. A set of weld conditions by type and thickness of material, which appeared to be optimum on the basis of external appearance, were defined. Since the equipment was of a new design, there was little known as to the effect of these variables except that each was dependent upon one or more of the others. Therefore, the development of the welding schedules for the various types of materials and material thicknesses would be strictly empirical. The effects of each variable were determined by changing one variable at a time while welding specific thicknesses or types of material. In this manner, the welding schedules were devised and the effects of the variables determined. The quality and strength of the welds was governed by the resistance welding military specification MIL-W-6858A, because presently there is no specification available covering gas tungsten-arc spot welding.

Two equal thicknesses of 0.030 in., 19 – 9DL material were selected as the first combination to be welded. The first attempt at establishing the weld current-time cycle was initiated by upsloping the welding current from 0 to 90 amp for 60 cycles. The total arc current time was preset for 120 cycles, and the current was allowed to decay to 0 over a time period of 180 cycles. The above time cycle sequencing was preselected on a basis of 60 cycle increments to determine if time schedules could be developed involving multiples of 60. If this technique proved feasible, it would help to simplify the development of future welding schedules for both varying weld joint thicknesses and different types of materials. However, as will be seen later, the time sequencing schedules developed used increments of 30 cycles instead of 60. The resultant weld in the 0.030 in. thick 19 – DL material, using the above schedule, had excessive penetration and a deep concave weld crater. However, the metallography investigation showed no cracks or other types of defects in the deposited weld nugget. After several more trail-and-error attempts to define the variables for this weld joint, a schedule was finalized and is depicted along with several other schedules for multiple joint thicknesses in Table 1. In multiple thickness welds, the two bottom sheets are usually the most important to check tensile shear strength because the nugget diameter at this particular interface will be the smallest between

Table 1—Gas Tungsten-arc Spot-welding Schedules

Material	Thickness, in. Upper	Thickness, in. Lower	Inert gas: Weld gun	Inert gas: Back up	Current, amp	Weld time in Cycles: Final slope	Wire start	Wire stop	Spot time	Tensile-shear, Avg. Arc spot, lb	MIL-W-6858, lb	Weld Arc spot	Diameter in., Mil-W-6858
19-9DL	0.030	0.030	100%A	100%A	75	120	30	60	300	1190	785	0.16	0.16
19-9DL	0.030	0.040	100%A	100%A	75	120	30	60	300	1150	785	0.16	0.16
19-9DL	0.040	0.030	100%A	100%A	75	120	30	60	300	1120	785	0.16	0.16
19-9DL	0.030	0.050	100%A	100%A	90	120	30	60	300	1265	785	0.18	0.16
19-9DL	0.050	0.050	100%A	100%A	120	210	150	240	600	2540	1855	0.23	0.21
19-9DL	0.040–0.030	–0.050	75% HC, 25% A	100%A	75	120	60	120	300	1430	785	0.20[b]	0.16
19-9DL	0.040–0.050	–0.050	75% HC, 25% A	100%A	150	120	90	150	390	2705	1310	0.20[b]	0.20
19-9DL	0.080–0.030	–0.050	75% HC, 25% A	100%A	150	180	150	240	540	3500[a]	785	0.25[b]	0.16
19-9DL	0.080–0.030	–0.080	75% HC, 25% A	100%A	200	180	150	240	540	3650[a]	785	0.25[b]	0.16
19-9DL	0.040–0.030	–0.080	75% HC, 25% A	100%A	225	180	150	240	240	3640	1310	0.30	0.20
Inconel	0.043	0.043	75% HC, 25% A	100%A	75	210	150	240	600	1858	1150	0.19	0.19
Inconel X	0.062	0.026	75% HC, 25% A	100%A	105	180	90	240	480	4637[c]	2595	0.24	0.24
Hastelloy X	0.062	0.062	75% HC, 25% A	100%A	105	180	90	240	480	2945	2595	0.24	0.24

[a] Tensile shear specimens in double shear.
[b] Smallest diameter of thinnest sheet.
[c] Annealed at 1950° F, double aged at 1525° F for 8 hr and 1325° F for 20 hr.

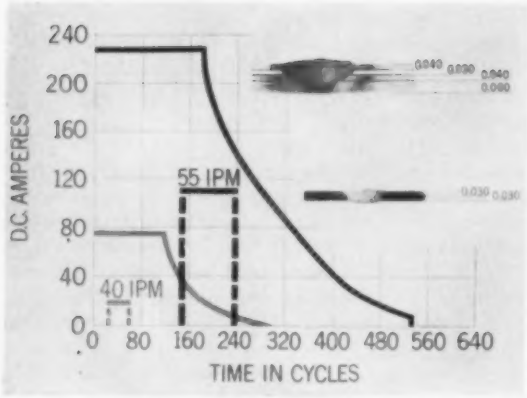


Fig. 8—Welding current time cycle for 19 – 9DL sheet material

any two sheets. This is due to the parabolic shape of the arc spot nugget. Table 1 depicts tensile shear specimens pulled to simulate the most severe conditions of stress anticipated for a specific component. Thus, the weld specimens were tested in single or double shear at particular layer, depending upon the application, and are noted in the Table 1.

The graphic weld time cycles and photomacrographs shown in Fig. 8 are for the two-ply and four-ply weld joint in 19 – 9DL material. It will be noted in this graph that the two-ply weld joint required additive filler wire before the final slope, while the four-ply joint required filler wire addition to continue for 60 cycles during the final slope.

The weld time cycle graph for arc spot welding 0.062 to 0.062 in. thick Inconel X and Hastelloy X is shown in Fig. 9. The graph illustrates that the same welding schedule was used for both materials. The consistent face-side and underside surface contour appearance on eight arc spot welds in 0.062 in. thick Inconel "X" is shown in Fig. 10.

The tensile shear valves for two-ply arc spot welds were approximately 33% greater than the minimum average strength specified in MIL-W-6858A.

Previous welding work on gas tungsten-arc spot welding has indicated that the maximum gap clearance between the sheets to be welded could not exceed 0.005 in. without affecting the physical strength of the weld. The gap clearances on all of the welding development work reported thus far in this report were maintained within this 0.005 in. limit. However, since the amount of filler wire fed into the weld puddle could be controlled with this

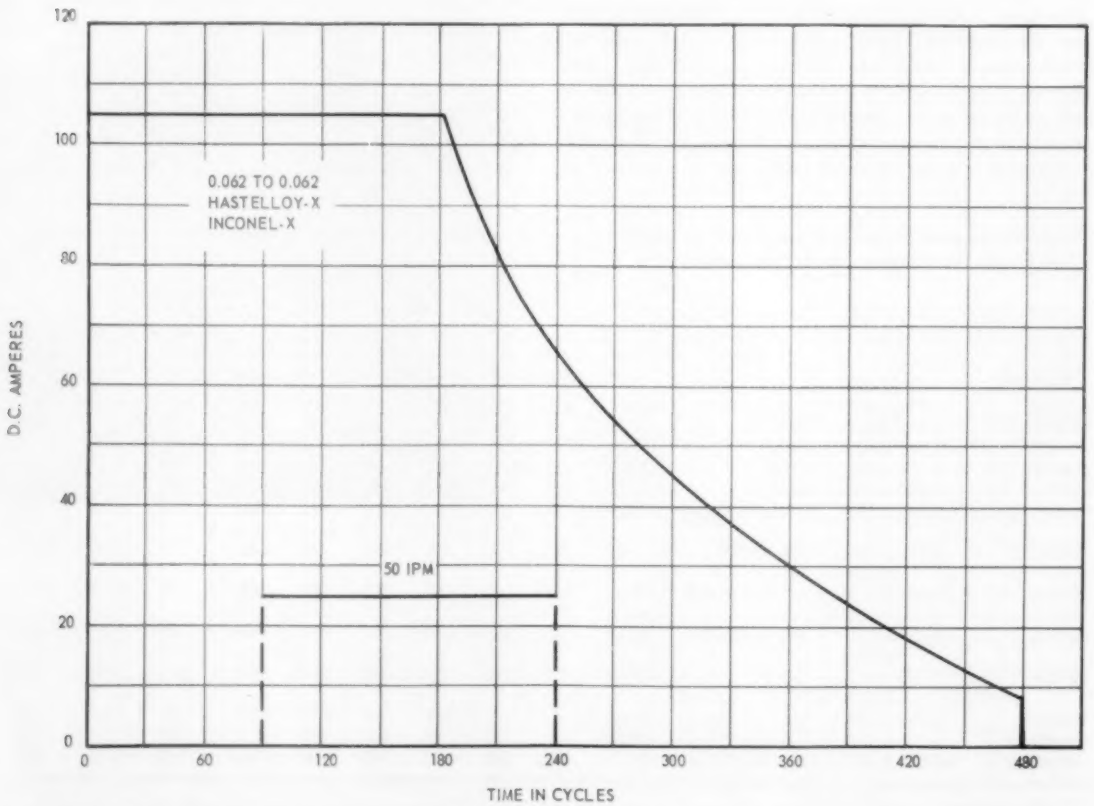


Fig. 9—Welding current time cycle for Inconel-X, and Hastelloy X, and 0.062 in. Inconel X

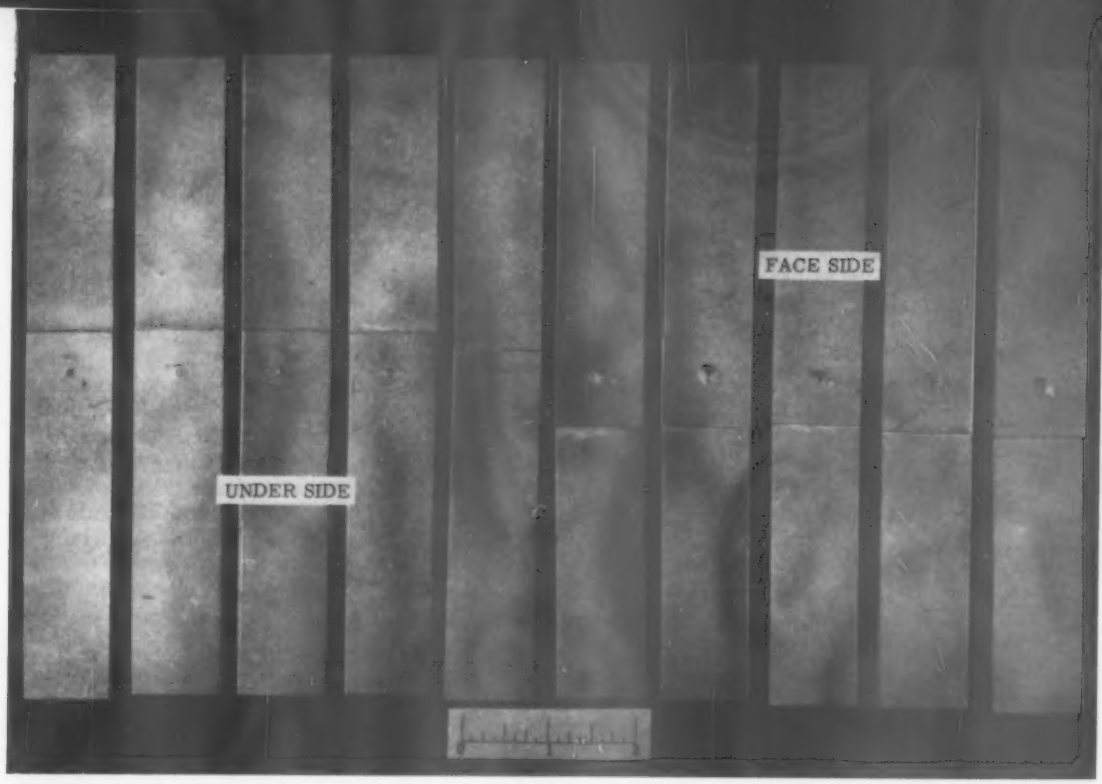


Fig. 10—Contour surface appearance of arc spot welds on 0.062 in. Inconel X

equipment, it was decided to investigate the feasibility of increasing this gap and still maintain the physical requirements of the weld.

Tests to determine the effects or the increased air gap were conducted using 0.030 in. thick Type 316 stainless steel. Spacers varying from 0.005 to 0.030 in. in 0.005 in. increments were placed between the test specimens to prevent the faying surfaces from coming into contact. Control settings that had been established for metal-to-metal fit were used throughout the test, except for the wire feed speed which was increased approximately 20% per 0.005 in. air gap increase. It was observed that on the 0.030 in. thick Type 316 stainless steel, arc spot welds could be made with gaps up to 0.025 in. (Fig. 11). The tensile shear values of these specimens exceeded the minimum requirements of military specification MIL-6858A by approximately 90%.

In order to control the fit-up conditions in production, an eddy current measuring gage was employed and a calibration curve of needle deflection vs. air gap was made and is shown in Fig. 12. Once the instrument is calibrated for a given material and thickness, it will yield an answer for only these conditions. Recalibration is necessary when there is a change in the thickness or type of material. Prior to making a weld, the welding operator uses this instrument to measure the air gap clearance between the two sheets so that he can then adjust the wire speed feed (ipm) accordingly.

Welding Shaver

In most aircraft fabrication it is necessary to remove weld build-up material to minimize the resistance to air flow passage. Since the face side

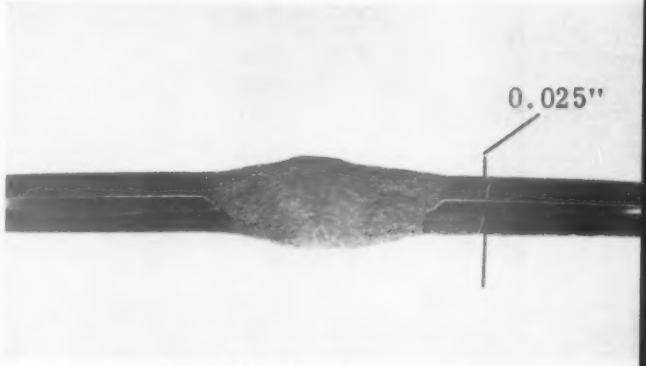


Fig. 11—Arc spot weld in 0.030 in. thick Type 316 stainless steel sheets with a 0.025 in. air gap

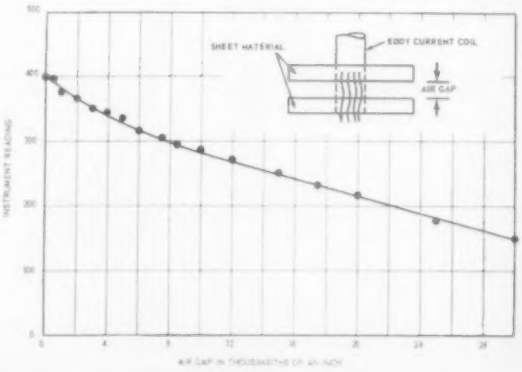


Fig. 12—Eddy current calibration curve for measuring air gap at the interface of two sheets

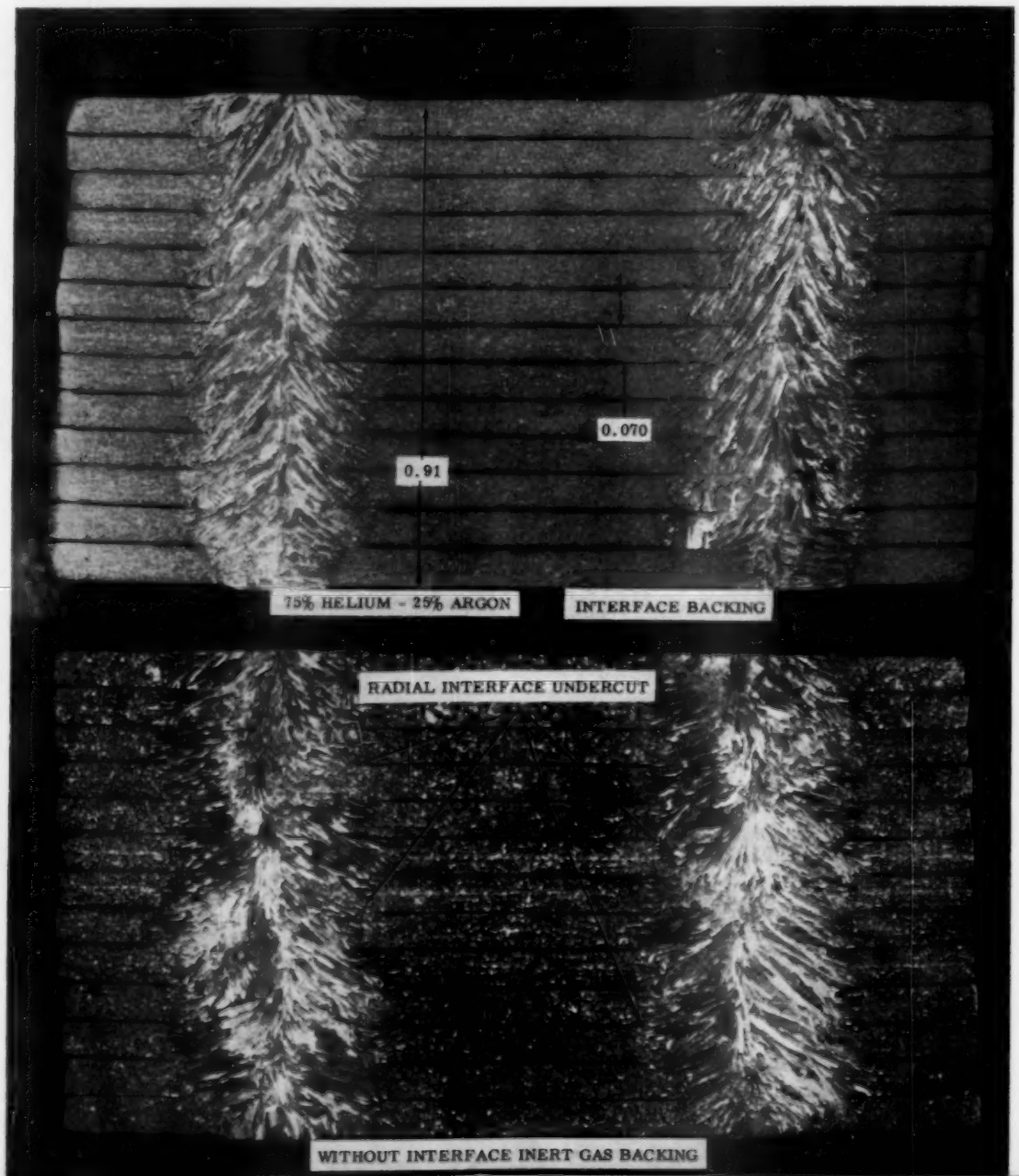
Fig. 13—Weld shaver used for removing weld build-up

of a weld deposit made by this process is slightly convex, a weld shaver (Fig. 13) was employed to remove this excess weld deposit flush with the surface plane. The adjustable cutter-roller combination on this tool permits preselected height control on all work, whether flat, concave or convex.

Design and Manufacturing Application

When considering the possible application of tungsten-arc spot welding, the designer and manufacturing welding engineer are faced with a number of considerations. First, what is the type and range of material thickness which can be handled with the process and how many sheets can be spot welded together? Furthermore, what is the relationship in

Fig. 14—Intermittent arc spot welding of thirteen 0.070 in. thick René 41 sheets



thickness between two or more sheets which are to be joined? A third consideration is the permissible center-to-center spacing of spot welds and also permissible spacing from the edge of the sheet.

It has been shown thus far that it is now possible to arc spot weld not only stainless steels but several other types of high temperature materials using the described equipment. It is the task of manufacturing welding engineers to determine two-ply joint thickness limitations by making mock-up joints and developing a welding schedule to determine the strengths and metallurgical results of the weld deposit. When considering multiple thickness joint limitations, the manufacturing welding engineer has two alternatives. He can attempt to weld the joint in one operation or revert to a sequence build-up. Figure 14 depicts a multiple pile-up joint consisting of thirteen 0.070 in. thick René 41 sheets. The joint was made by sandwiching two sheets together and making the arc spot welds at the two locations. The face of the weld was flushed using a weld shaver, and the next sheet was placed into position and welded to the first two sheets. This method of manufacturing stack-up continued until all thirteen sheets were joined together. It is of interest to note that it was necessary to shield the interface surfaces with an inert gas to eliminate the radial undercutting on the backside of the top sheet. In the materials described, there is no minimum center-to-center distance of arc spot welds except that the spacing should be as large as design considerations permit in order to minimize weld distortion.

A combined resistance and arc spot welded panel is shown in the lead photograph with a cut-out view of the arc spot weld underbeads. The welding operator shown here is measuring the air gap between two 0.030 in. thick 316 stainless steel sheets prior to welding, and Fig. 15 shows the welding operation. This particular structure was sealed and purged with argon gas before the first arc spot weld was made. A combination of a resistance and tungsten-arc spot welded test panel is shown in Fig. 16.

Although the equipment was designed for the tungsten-arc spot welding of sheet materials, it has proved to be quite useful for other applications. With some slight nozzle modifications on the welding gun, the unit has been used for a deep hole plug welding operation of a Hastelloy X sleeve welded to a Type 304 stainless steel sheet shown in Fig. 17. In an attempt to minimize weld distortion as compared to other joining processes, the unit was employed to join a 0.030 in. thick 19-9DL sheet to a $^1/_2$

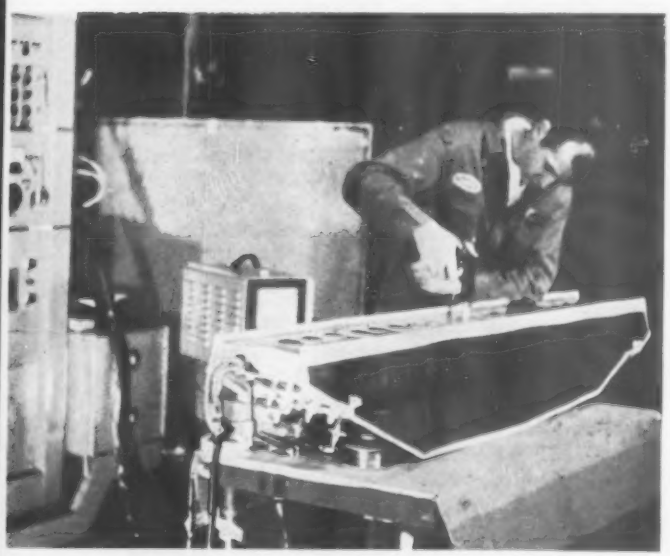
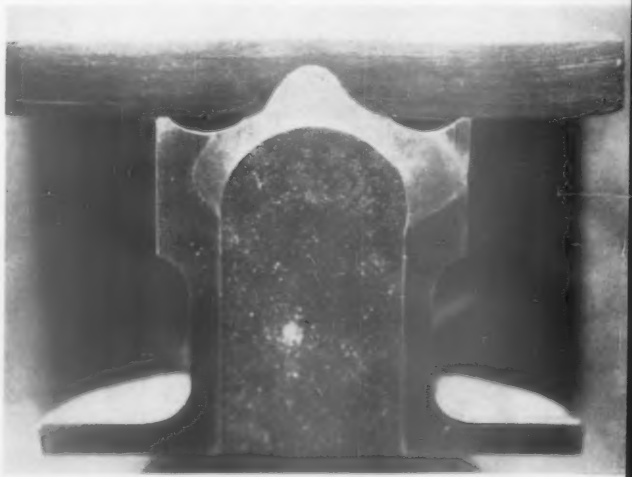


Fig. 15—Arc spot welding of a Type 316 stainless steel container

Fig. 16—Resistance and arc spot-welded test panel

Fig. 17—Photomacrograph of an arc spot weld between a Hastelloy X sleeve and a Type 304 stainless steel sheet. ×8. (Reduced about 60% on reproduction)



in. diam Type 304 stainless steel tube with a 0.020 in. wall thickness (Fig. 18). A photomacrograph of a cracked resistance welded four ply 19 – 9DL weld joint repaired by tungsten-arc spot welding is shown in Fig. 19.

Conclusions

From the data presented in this report the following conclusions are made:

1. Gas tungsten-arc spot-welding equipment is now available to arc spot high temperature alloys without crater cracking.

2. Since a basic knowledge of the process has been acquired, equipment settings and welding techniques for various joint thicknesses can be established.

3. Weld strength, size and quality can be consistently produced on welds made in high temperature materials.

4. It is feasible to make tungsten-arc spot welds which have fit-up gaps exceeding 0.005 in. between sheets.

5. Different types of shielding atmospheres are required depending upon the weld joint thickness and type of material.

6. Sequence timing of adding the filler wire into the weld puddle is a function of the type of material and the total thickness of the weld joint.

7. For tungsten-arc spot welding the materials described, a two diameter taper on the 0.125 in. diam tungsten produced the minimum of electrode erosion.

8. Its been demonstrated that the process can be used for deep hole welding operations and the repairing of cracked resistance welds.

Recommendation

Information gained by investigation of the gas tungsten-arc spot-welding process indicates a need to establish the following:

1. The effect of ceramic back up coatings in controlling weld nugget shapes.

2. The effect of gun nozzle design as a heat-sink to control weld distortion and weld nugget configuration.

3. The effect of high initial current with corresponding current decay in controlling localized weld distortions.

4. The effect of interface inert gas shielding on the strength and nugget configuration of the deposited weld.

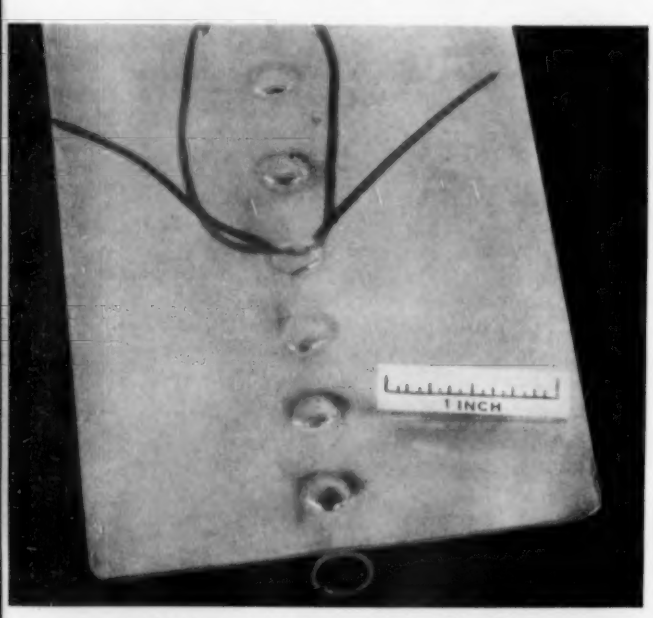


Fig. 18—Arc spot welding a sheet to tube joint

Acknowledgments

It is to the following individuals of the Aircraft Nuclear Propulsion Department, General Electric Co., that acknowledgment is paid for the helpful assistance and information needed for the completion of this paper: Willard Lewis, welding experimental detail; Ivan Miller, metallography; Gerald Reagon and Richard Pucci, photography; Thomas Capizzi and Kenneth Stahl, project discussion; Rose Merckle, art work; and also to Allen Peterson, of the Welduction Co., Detroit, Mich., who supplied informative equipment data.

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Fig. 19—A cracked resistance weld repaired by arc spot welding

Repair of Kraft Digesters by **Welded Overlay**

requires sound welding techniques and more suitable welding materials to avoid past failures due to poor weld metal chemistry

BY WAYNE L. WILCOX AND HALLOCK C. CAMPBELL

The restoration of kraft paper digesters poses several problems. Some are quite unusual from the welding point of view, while others are those with which the welding industry has long been familiar. The familiar problems seem to be the troublesome ones at the present time, and much ingenuity will be required to find a suitable solution.

The digesters here considered are huge, cylindrical, batch-type pressure cookers which stand vertically. They usually have a dished upper head and a cone-shaped bottom. They range in over-all size from 40 to 90 ft. in height. Some are up to 12 ft. in diam. Although the wall thickness decreases with use, it is usually at least $^5/_8$ in., with $^7/_8$ in. being not uncommon. A new carbon steel digester with considerable corrosion allowance may have a wall as thick as $2^1/_2$ in.

The cost of a new carbon steel digester ranges from about $12,000 for a small one to more than $50,000 for a large vessel with $2^1/_2$-in. wall. A clad digester of the same size would cost $60,000 to $100,000 or more.

Originally the life expectancy of a digester was about 20 years, but changes in cooking techniques, increased temperatures and pressures, and "round-the-clock" use are believed largely responsible for the often experienced reduction in life, now quoted as less than eight years.

Many of the vertical digesters have been completely installed within a building or framework, making it desirable, when repair is necessary, to effect a serviceable repair with the digester in position.

Early attempts at digester repair consisted of applying a stainless steel sheet or strip lining, welded in place with spot, plug or lap welds. Unfortunately, since the sheets could flex with changes in pressure and temperature, linings so applied ended in disastrous failure through fatigue. Failure occurred near the welds in the protective lining, resulting in penetration of the liquors into the carbon steel wall of the digester.

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This experience pointed up the need for an integral lining, such as a weld overlay, to provide a serviceable lining of minimum thickness.

Both manual and automatic repairs of this nature have been accomplished. The equipment for automatically welding those digesters which must be repaired in position has been designed to be taken apart and lowered into the digester through a 24-in. manhole. Both submerged-arc and gas-shielded-arc welding are accomplished in the three o'clock position. On one digester which could be positioned, an overlay was deposited with the series submerged-arc technique.

Digester Statistics

It is estimated that there are 1300 kraft digesters in North America, of which some 1050 are the vertical stationary type and the remainder are a tumbling or rotary type—Table 1.

The initial digester overlay repairs of integral type were made about nine years ago. In the ensuing nine years, according to the statistics collected for the Corrosion Committee of the Technical Association of the Pulp and Paper Industry (TAPPI) by

Table 1—Classification of the 1300 Digesters in North America

No.	Process	No.	Construction
900	Kraft	1050	Vertical, stationary
80	Soda	250	Tumbling or rotary
80	Semichemical		
240	Rotary		

Table 2—Classification of 260 Digesters Overlayed by Welding

Location of repair	No.	Method	No.
Complete surface	5	Automatic welds	120
Shell and bottom	25		
Shell only	70	Manual welds	160
Bottom only	7		
Top dome	3		
Patched	150		

Fig. 1—Upward view within a typical kraft digester. Diameter of vessel is 12 ft. Scaled area below the nozzle is about 5 ft high. White portion of vertical wall has been severely attacked by wash action and pitting. Light gray area has suffered mild attack

Fig. 2—Closer view of top dome showing white liquor nozzle and distributor ring

a firm prominent in the application of digester overlays, it is estimated that weld linings, partial or complete, have been applied to 260 digesters. Of these, 120 were made with one of the automatic welding processes, and 150 with coated electrodes applied manually—Table 2.

A view upward from within a typical digester is shown in Fig. 1. In overlaying this digester in May 1957, the gas metal-arc process was used with $^1/_{16}$-in. diam Type 310 electrode wire to deposit a layer of weld metal about $^1/_8$ in. thick. The overlay has suffered rather extensive corrosion attack, which in part was attributed to a crack in the white liquor nozzle, permitting a steady drip or wash of the liquor down the sides of the shell. The white liquor nozzle and the distributor ring are visible at the top of the digester. These are shown at closer range in Fig. 2. Figure 3 shows severe pitting attack and penetration into the stainless overlay. Figure 4 is a closer view of a 12- x 18-in. area.

How many of these overlays have failed to give completely satisfactory service? In the survey for the TAPPI Committee, 70 overlays were investigated—Table 3. This is a generous sampling, representing about 27% of all the welded overlays known to be in service. Of those deposited by either of the automatic processes, 28 out of 53 had suffered from corrosion or other defects in 5 or 6% of the area overlayed. Of the manual overlays, 7 out of 17 digesters had suffered corrosion attack in 5 to 6% of the overlaid area.

If this is a representative sample, we may expect that 40 to 50% of the existing overlays not included in the survey have suffered corrosion attack. That is an alarming number. To keep the picture in proper perspective, however, it should be pointed out that in this survey no digester was reported to have suffered total or complete failure throughout all

Table 3—Corrosive Attack Revealed by 70 Digester Overlays

	Method of Welding		Degree of Corrosion	No. of Cases	Extent of Attack
	Automatic	Manual			
Number welded	53	17	Total failure	None	...
Number corroded	28	7	Extensive attack	1	72% of overlay
Extent of welded area attacked	5 to 6%	5 to 6%	Moderate attack	21	10 to 20% of area, in 1 to 4 years

of the overlay. The poorest showing seems to have been made by the digester shown in Fig. 1, which suffered attack on 1050 sq ft of the 1300 sq ft overlayed. (The total interior surface of a large digester exceeds 1800 sq ft.) In 30% of the digesters studied for the TAPPI Committee, the liquor had attacked 10 to 20% of the overlay in a matter of 1 to 4 years.

Corrosion Problems

There is great uncertainty about many facets of the digester overlay problem, but it is believed, even with its complexities and despite the uncertainties of the moment, that the problem will prove to be soluble by a rational approach. There is uncertainty, for instance, surrounding the actual composition of the kraft cooking liquor. The solutions vary in composition and concentration. There are hot sodium sulfate liquors and hot alkaline sulfide liquors; the digesters are operated at different temperatures and charged with various woods.

Traditionally, Type 316 stainless steel has been the digester steel, because of its resistance to the sulfur acids and to pit-type corrosion. It is true, however, that the specific need for a molybdenum addition to the digester overlays here discussed has not been proved. There is, in fact, some indication that, as an alloying element, it may not be necessary; the success of properly deposited moly-free weld metal from Type 310 coated electrodes and the some-degree-of-success achieved with similar automatic welds cannot be completely ignored. It is the premise in this paper, however, that the experience associated with the Type 316 alloy should be useful in solving this problem for which, under somewhat less severe conditions, carbon steel once was adequate. It is a further premise in this paper that the most serviceable overlay will result from a deposit which, in addition to being "chemically right" for corrosion resistance, is "chemically right" for weld soundness. To meet this latter requirement, based on the present-day state of the art, the weld should contain a small amount (perhaps 4 to 10%) of delta ferrite, to guard against fissuring and cracking.

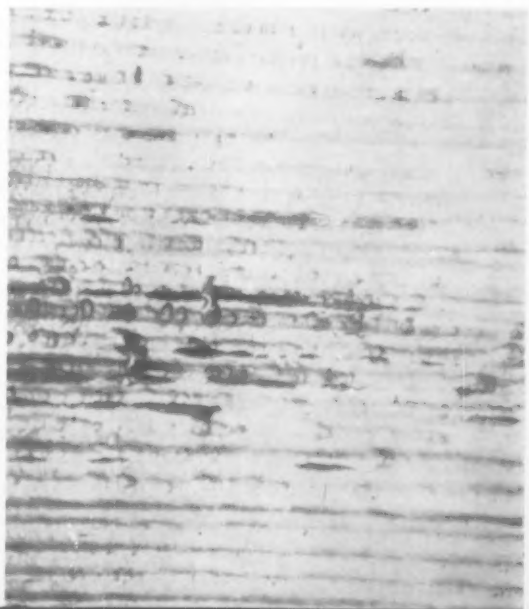
In the past, Type 310 coated and bare electrodes (and the molybdenum modifications thereof) have been used almost exclusively. With any of these materials it is impossible, considering the dilution rates involved, to obtain any ferrite at all in the deposit. Cracks and fissures must have been prevalent in these welds, even though some of the overlays have been considered successful—if only for a relatively short time. The characteristic corrosion pattern of these welds betrays the location of the fissures in the deposited metal.

After investigating several faulty overlays, it is felt that failures can be explained by the lack of success in consistently obtaining a sound deposit uniformly sufficient in alloy content to resist corrosion. Figure 5, for instance, presents a close-up view of a 3- x 3-in. area of the digester in Fig. 1.

Fig. 3—Area approximately 18 x 24 in. located 12 ft below white liquor nozzle. Severe pitting attack and penetration of the stainless steel overlay are revealed by shadows and dark rust stains

Fig. 4—Area approximately 12 x 18 in., from same location as Fig. 3. Attack follows paths which resemble transverse and longitudinal cracks in weld beads

Fig. 5—Close-up view of severely attacked area (3 x 5 in.). Horizontal pitting corresponds to heat-affected zone of each bead. Longitudinal penetration seems to have followed weld bead cracks



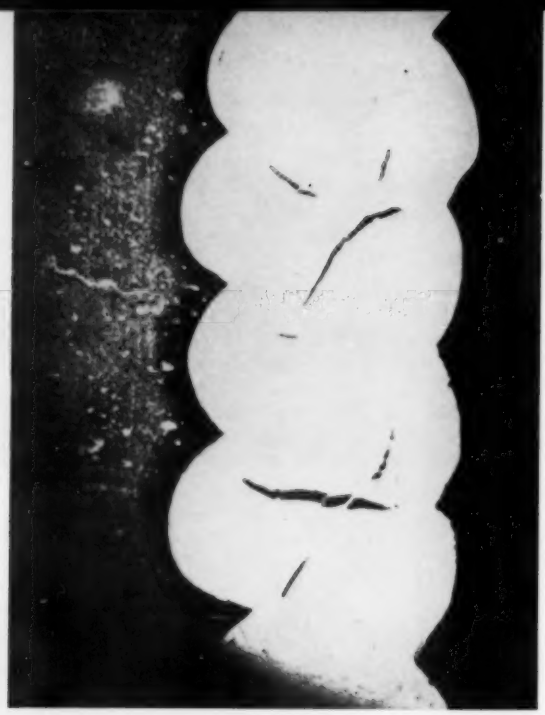


Fig. 6—Cross section of digester overlay applied with submerged-arc process. Severe fissure-type cracks within the body of the bead are typical of fully austenitic weld cracking. Vilella's etch. × 5

Extensive pit-type corrosion is visible along many of the beads. Since these beads have been attacked in the heat-affected zone produced in each bead by the succeeding pass, the chemical composition of the beads must have been too low in chromium to withstand the corrosion attack, especially after sensitization. In this digester and others, attack occurred in a wash area where the liquor was permitted to run down the walls of the vessel. A richer weld deposit chemistry might have resisted this attack. Where attack has been reported on apparently sound overlays of good chemistry, the cause has often been traced to a liquor wash or drip; when the drip has been corrected, the attack reportedly has ceased.

Other Corrosion Failures

On other overlays, attack has occurred frequently in the form of undercutting at the boundary between the overlay and the carbon steel wall. This is a design problem, which suggests extending the overlay further out—even throughout the vessel.

Localized attack is inevitable where weld beads have failed to overlap properly. At such locations the carbon steel may actually have been exposed. If it was only thinly covered with weld metal, the

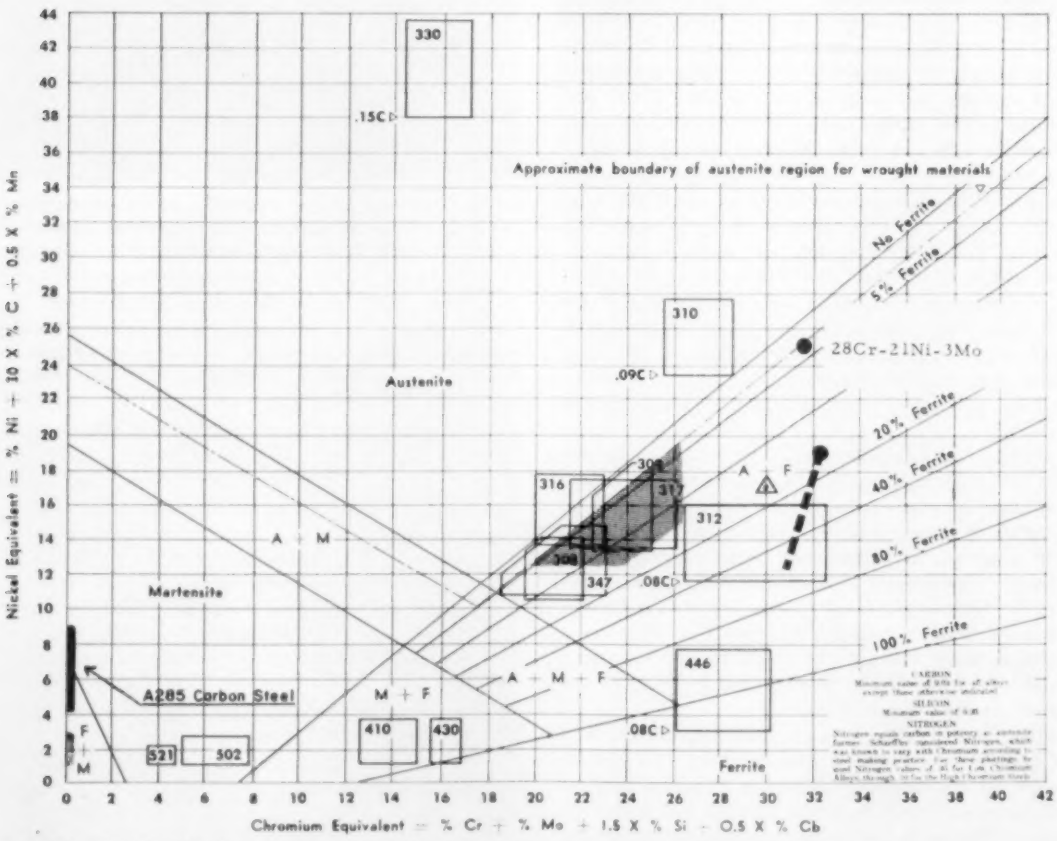


Fig. 7—Schaeffler Constitution Diagram. Shaded area is recommended weld overlay composition range

alloy content of the adjacent bead next deposited was probably too low due to increased dilution.

Erosion attack is evident in many digesters at points of impingement of the pulp on the walls of the vessel. Here again a change in vessel design to avoid the impingement of the pulp on the walls of the vessel has been helpful.

Corrosion attack has often followed paths which seem to have been weld cracks. Transverse cracks led to penetration patterns of the type shown in Fig. 5 and to longitudinal cracks to the more extensive penetration shown in the same view. Judging from the unbalanced chemical composition of many overlays, it seems inevitable that the cracks must have existed from the moment the weld was made.

It is true that inspectors have critically examined the surface of certain welds and reported them to be sound. Figure 6 shows the condition which may have existed in many such welds. This photomacrograph is a 5-fold magnification of a transverse section through an overlay made in the three o'clock position by submerged-arc welding. The photomacrograph reveals in the weld metal the existence of transverse and longitudinal cracks which were undetectable from the surface. A "sound" weld of this nature, particularly one low in alloy content (and therefore low in corrosion resistance and perhaps low in ductility), would soon deteriorate in service and permit the liquors to penetrate to the mild steel backing.

Proposed Weld Compositions

The Schaeffler Diagram in Fig. 7 will serve to coordinate the discussion of materials which have been used for digester repair. The Schaeffler Diagram has been used for years for estimating the microstructure of a stainless steel weld deposit on the basis of chemical composition. For instance, it can be used to predict whether a deposit will contain ferrite, a structure known to impart resistance to weld cracking; or, when the dilution rate is known, to predict the electrode composition necessary for producing ferrite and avoiding martensite, for maximum weld metal ductility.

The two axes of the diagram represent "equivalents" of chromium and nickel respectively. The "chromium equivalent group" includes chromium and the elements silicon and molybdenum, which act like chromium microstructurally. The "nickel equivalent group" includes nickel and the elements carbon and manganese, which act like nickel. A blanket allowance is made for the nitrogen content of standard weld metals, based on steel mill and electrode making practices.

The compositions desirable in a digester overlay are found in the shaded area superimposed on the 308-316-317 portion of the diagram.

The base metals for digesters have usually been A212 and A285 carbon steel, with 0.15 to 0.30% carbon for the most part. On the Schaeffler Diagram these steels lie in the shaded area near the origin. A tie line connecting this area to any filler metal composition will indicate the welds resulting from that combination, at all possible dilution rates. If the percentage dilution is known, the weld microstructure will be shown along the tie line at that dilution percentage point.

The diagram indicates that overlays with Type 310 wire would all be fully austenitic, regardless of dilution. They would therefore be expected to be sensitive to hot cracking. Welds have been made recently with 310 Mo wire. These also would be fully austenitic at all dilution levels (within practical limits) and, therefore, would also be more susceptible to hot cracking than a partially-ferritic composition.

Deposits with 310 Mo coated electrodes, and some of those with the standard moly-free grade, have given good service performance. In each case the lower dilution rates associated with properly applied manual electrodes no doubt have contributed to the good results; chrome-rich deposits should have better corrosion resistance. Those cases which were not successful are again suggested to have been probably full of microcracks before they went into service.

In order to increase the general alloy content of deposits made with the automatic processes, the increased dilution rates obtained with those processes must somehow be offset. One means of doing this is through the use of a more-highly-alloyed wire. The composition indicated as 28Cr – 21Ni – 3Mo in Fig. 7 is such a wire. It lies far enough to the right on the Schaeffler Diagram to approximate a 316 weld deposit after 33% dilution. Several heats of this analysis actually have been prepared and with considerable difficulty reduced to wire form. The availability of this type of drawn wire will always be poor at best, as will be explained shortly. However, sufficient wire was made available early in 1960 to overlay several digesters. The corrosion resistance of the overlays applied with this

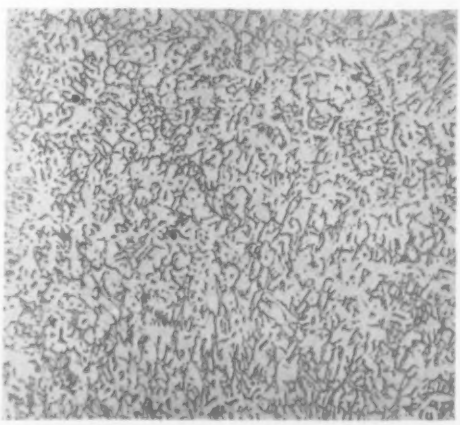


Fig. 8—Microstructure of first layer overlay containing austenite and 15–17% ferrite. Kalling's reagent. × 250

wire remains to be tested. Obviously the inspection reports from these digesters will be watched with interest over the next four or five years.

The triangle in Fig. 7 locates another wire composition, which theoretically was desirable but which could not be produced by the steel mills, even those with great experience in handling 29/9 and other similarly difficult steels. Several small heats of 26/16/3 Mo were completely lost in the billet, because of cracking from sigma phase embrittlement.

The circle at the end of the dashed line in Fig. 7 shows a similar composition achieved by making an undiluted submerged-arc weld. The wire was the Type 312 composition shown at the lower end of the dotted line. The weld was reinforced, through the flux, with the alloys required to arrive at the upper end of that dotted line. Because of the nature of the chromium, nickel and molybdenum reinforcement in this flux, the all-weld-metal composition included approximately 26% Cr, 16% Ni, and 5% Mo.

The intention, in this experiment, was not just to produce the resulting undiluted weld metal composition, but to build a wire-flux combination which would give the partially ferritic-Type 316 stainless steel deposit preferred for the overlay, when diluted as it would be in a single layer overlay on a carbon steel digester wall. In designing such wire-flux combinations, it is helpful to think in terms of undiluted weld metal chemistry. For this reason the present undiluted weld pad was made in the flat position, with no attempt to simulate the dilution obtained in the 3 o'clock position. The first layer (the most highly diluted) contained 15 to 17% of ferrite in a matrix of austenite—Fig. 8.

The microstructure of the nondilution top layers of this pad is of great interest metallurgically, as it shows the hopelessness of ever achieving a wrought wire of this composition. The microstructure was almost 100% sigma phase! The typical area shown in Fig. 9 was taken from the third layer of the nondilution pad; this pad cracked loudly during normal cooling from the welding temperature.

The presence of sigma in an as-deposited weld bead is intriguing but alarming. There have been reports before this of the rapid formation of sigma in alloys during heat treatment or in multipass welding, but it is believed that this is the first time so much sigma has been reported in a newly deposited bead in the as-welded condition.

Fig. 9—Nondilution microstructure which cracked loudly during welding. Composition is almost fully sigma, with some austenite at the original grain boundaries. Analysis is 26Cr – 16Ni – 5Mo. This is section through third layer of a weld pad, as deposited. Murikami's etch, cold, concentrated. × 250

If the diluton expected in these overlay welds thus causes one to extrapolate from the desired 316 area to a "wire" composition in this 26 – 16 – 3Mo area, it is obvious, since solid wires are not commercially feasible in a composition which transforms readily to the brittle sigma phase, that such a wire must be of a synthetic, composite type, or a submerged-arc wire-and-flux combination. The economics of the situation probably will favor the composite wire.

Conclusions

The authors feel that most of the failures experienced so far with weld overlays in digesters can be attributed to poor weld metal chemistry. This is reflected in the corrosion pattern itself, and in the cracks and defects noted.

The solution would seem to lie in the establishment of sound welding techniques and the use of more suitable welding materials.

First, the deposition of the overlay must be controlled so that proper bead overlap and sound welds of uniform thickness and chemistry are obtained.

Second, the dilution rate must be uniform and at the lowest practicable level. Penetration, which drastically affects the dilution rate and the weld carbon level (especially in relatively thin weld deposits) can be reduced by use of the proper combination of wire angle, bead overlap, I^2R heating and travel speed. A cold wire feed might also reduce dilution, but the equipment required is cumbersome. The added time required to deposit weld metal with techniques that give low dilution rates in the 3 o'clock position has been considered unacceptable. Economically, the preference would be to compensate for dilution by increasing the alloy content of the wire; this suggests a fabricated wire or a reinforced submerged-arc flux.

Third, no matter what the technique, the proper wire for gas-shielded arc welding and the proper wire-flux combination for submerged-arc welding must be used. The optimum wire or wire-flux composition will depend on the dilution rate finally encountered in the attempt to economically balance deposition rate and dilution. One such composition has been suggested.

The entire problem is very complex. Nevertheless, the authors would like to express the feeling that quality welding (with special wires to give a weld metal chemistry inherently sound and of sufficient alloy content) will provide a satisfactory solution to the repair of kraft digesters.

Acknowledgment

The authors are indebted to Zane S. Blanchard, Portland Overlay Welding Div., Chicago Bridge and Iron Co., for making available much of the tabular information quoted in this paper.

Practical Welder and Designer

Fig. 1—Operator uses heavy-duty welding gun at PFE's maintenance shops in Los Angeles to join the car sides to the sills. Carbon dioxide for the operation was supplied by a portable liquid receiver

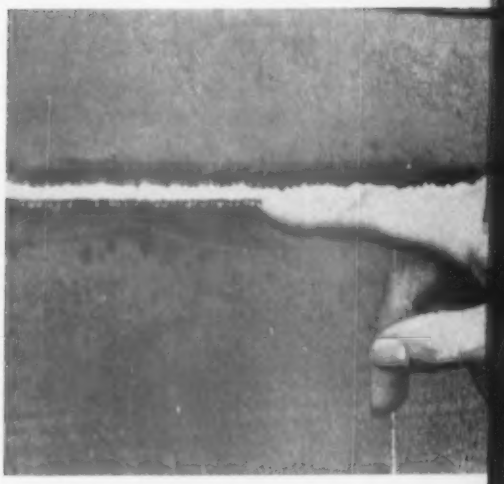


Fig. 2—Finished weld on side of new PFE refrigerated car

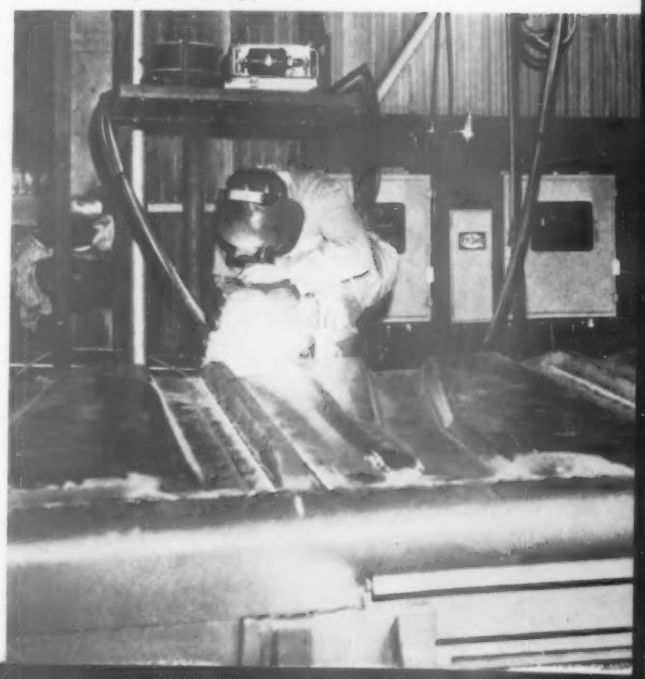
CO_2 Welding Equals 1025 Refrigerated Cars

A recognized leader in mechanically refrigerated railroad cars, the Pacific Fruit Express Co. helps keep its top ranking by seeking better ways to improve service. Recently, PFE completed construction of 1025 multipurpose 50-ft. long refrigerated cars—welded with the carbon-dioxide-shielded metal-arc process—which are expected to provide greater incentive to shippers.

Twenty-five of the new units are designed especially for transporting commodities requiring temperatures between 32 and 70° F. All 25 cars, with additional features other than high-temperature range controls, are now in service. From these special cars, a new design for a "refrigerator car of the future" may result. The remaining 1000 new cars are equipped with refrigeration units capable of maintaining constant temperatures ranging from 0 to 70° F, for periods up to twenty days without refueling. These cars are equipped to handle all types of fresh fruits and vegetables as well as frozen

Based on a story from the Air Reduction Sales Co., New York, N. Y.

Fig. 3—Welder joins galvanized roof sheets to the car using CO_2 welding process



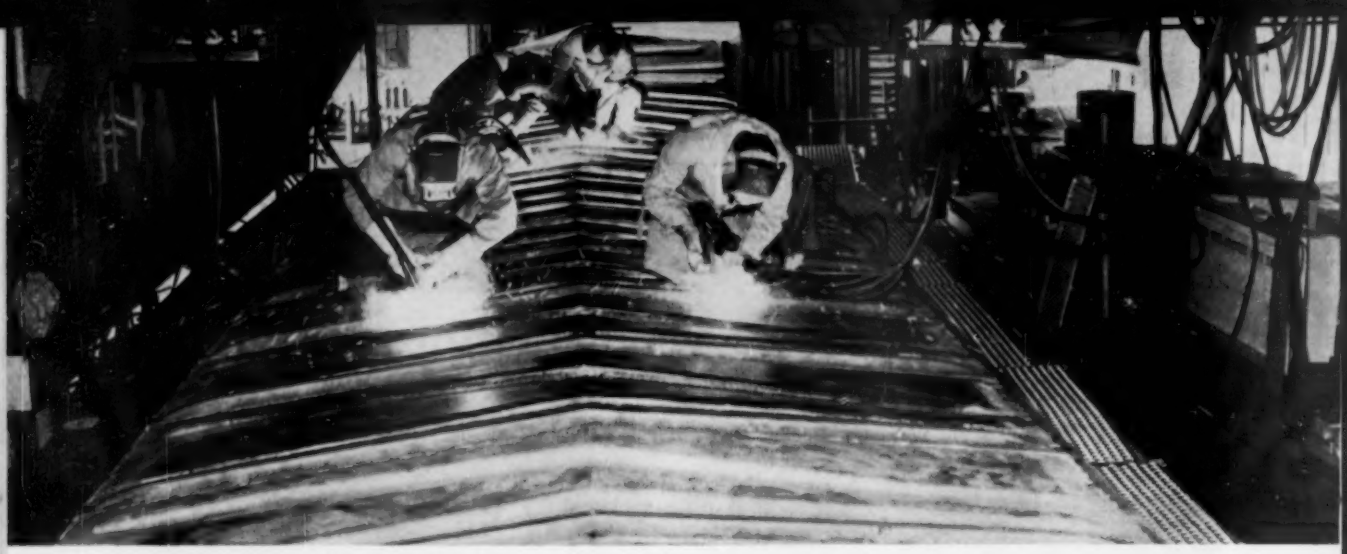


Fig. 4—Operators atop PFE cars finish roofing operation with CO_2 welding process

Fig. 5—Finished car ready for service

foods, providing protection against heat or cold as required.

The new equipment is very attractive to perishable item shippers and receivers, as well as shippers of nonperishable products in westbound movement. All these units are equipped with roller bearings, protective load dividers, and 8-ft wide doors to facilitate lift-truck loading and unloading.

Selection of the carbon-dioxide-shielded metal-arc process for welding of the new fleet of refrigerated cars come after PFE did considerable testing with various welding equipment. Prefabricated subassemblies, furnished by several suppliers, were shipped to PFE's maintenance and construction shops in Los Angeles for final fabrication.

Two stations were set up on the assembly line at the shop to accomplish welding operations on the 70-ton capacity cars. In the "side-sill" operation, welding of the prefabricated sides to the car sills, two heavy-duty guns were used. The appropriate 0.035-in. diam wire was employed in welding approximately 100 lineal feet on each car.

The units then rolled on to the final station where galvanized roof sheets were welded in place. Six heavy-duty guns and suitable DC power sources were utilized in this roofing operation. About 300 lineal ft of welding were required, using the A675, 0.045-in. diam wire.

A total of 500 lineal ft of welding was required in the total operation on each car, taking approximately 30 min and 40 lb of wire. Carbon dioxide gas was piped to each welding station from two, $2^1/_2$-ton portable low-pressure receivers at the rate of 35 cfh.

Cutting Torch Rotating Machine Speeds Weld Preparation

A new rotary oxygen torch cutting machine that reduces welding preparation costs 45% in manufacturing marine steam generating equipment has been developed recently. Used in manufacturing marine boiler steam drums, the portable oxygen cutter prepares the cylinders for the attachment of elliptical drum ends.

The new machine burns through the ends of cylinders which cannot be rotated on turning rolls. Cutting away 4 or 5 in. of steel, it replaces a conventional machining operation that took approximately three times as long.

Based on a story from the Foster Wheeler Corp., New York, N. Y.

The oxygen cutter was designed and built by Foster Wheeler plant engineers from a modified Ransome No. 10 Positioner. The unit, which rotates cutting torches around the cylinder ends, is equipped with casters for primary positioning and jacks for anchoring and leveling. A cross slide permits movement of the mast for secondary positioning.

Fuel gas and oxygen headers with regulators for oxygen cutting pressure are attached to the unit's base. The headers feed two machine cutting torches and a hand torch. An adjustable torch bar fixture consisting of a screw counterweight, personnel

Fig. 1—Used in manufacturing marine boiler steam drums, the portable oxygen cutter prepares the cylinder, shown above, for the attachment of an elliptical drum end

Fig. 2—Here, a workman cuts a taper through the wall of a drum shell used in marine steam generating equipment

shield and a pointer for aiming the oxygen cutter is bolted to the face plate of the positioner. High-speed, divergent oxygen nozzles with oxy-propane cutting tips are used. The positioner was modified to include an electric sweep second hand for setting cutting speeds and a locking adjustment for swiveling the positioner on the mast.

A cylinder to be oxygen cut is layed out allowing $^1/_4$ in. at each end for final machining of a weld groove preparation. With the cylinder mounted on "V" blocks, the excess steel is burned off by the oxygen cutter.

An operator can lay out inside and outside tapers and cut both simultaneously. Depending on the diameter of the cylinder and design pressure requirements, the tapers have face widths of from 2 to 9 in.

The quality of the burned surfaces is reported to be excellent—requiring only slight wire brushing to clean away small quantities of oxide scale after slag removal.

Heavy Composite Column is Shop Welded for Building

An unusual main column for a 19-story all-welded bank building in Charlotte, N. C., has composite construction to carry heavy compression and bending loads. To be occupied by the North Carolina National Bank, the building has six main columns along each side, supporting 56-ft girders, spandrels and floor beams. Field assembly was by temporary bolting and welding, using both manual and semi-automatic submerged-arc techniques.

The columns have ten sections each, ranging in length from 20 to 47 ft, some as heavy as 27 tons. Each section carriers two tiers of floors, and splices were welded progressively as the building rose. The main tower section columns were welded in the shops of Bristol Steel and Iron Co., Bristol, Va., some 300 miles away, and were rail shipped to Charlotte. The Southern Engineering Co. of Charlotte, the prime steel contractor, shop fabricated the service tower structural members. Core sections of the main tower section are 36 WF beams, ranging in weight from 280 to 369 lb per ft, and have heavy wing plates fillet welded to the inside flange and a cover plate over the outside flange. In addition, there are torque plates at each girder framing point,

Based on a story from The Lincoln Electric Co., Cleveland, Ohio.

plus assorted tie plates, stiffners and other reinforcements.

A total of 3558 tons of steel went into the structure along with 210,000 lb of welding electrode, flux and wire for semiautomatic and full automatic welding equipment used in both shop and field. The application of mechanized ML-3 "Squirt" welding guns in the field was noteworthy. Another 608 tons of steel will be needed in a four-story "skirt" to be built up around the base of the building, starting next fall.

General contractor for the project was Southeastern, Goode, Thompson and Street Co.; the architect was Walter Hook and Associates; and the structural engineer was Ray V. Wasdell and Associates, all of Charlotte. Norfolk and Western Railway had responsibility for shipment of steel from the Bethlehem mill at Sparrows Point, Md., to Bristol and from there to Charlotte. In the latter phase, Seaboard Air Line and the Piedmont and Northern Railway cooperated.

Better Docks for Better Boating

A fastening process that saved millions of dollars for wartime shipbuilders has helped to cut the cost of an important piece of equipment for America's fastest growing sport—boating.

Stud welding, which involves welding fasteners or projections of steel or aluminum with a semiautomatic portable gun, was originally used during World War II to secure wood decking on ships. Recently it performed a similar function on free floating boat docks made by The American Tower Co., Shelby, Ohio.

The studs were welded vertically to the 16-gage tubular steel side rails of the docks and 1-in. oak planks with predrilled holes were then placed over the studs. Studs can be welded almost twice as fast as alternative fasteners could be applied, it was estimated by American Tower's president, C. J. Wingart. Special "J"-bolts, tried experimentally, opened up and eventually were lost. With "J"-bolts, moreover, holes had to be countersunk in the planks for nuts. This operation was eliminated with studs and Nelson "T" nuts, which bit into the wood until they were flush with the surface.

During stud welding, the 10-ft rail tubing rode on a fixture that stopped at intervals of 4 in. beneath a fixed Nelson production unit. Twenty-eight studs, $^1/_4$ in. in diam and $^7/_8$ in. long, were end-welded in approximately 7 min. to each length of tubing.

Based on a story from the Nelson Stud Welding Div., Gregory Industries, Inc., Lorain, Ohio.

Fig. 1—Floating, easily-moved docks were made and assembled more easily and economically because of end-welded Nelson studs

Fig. 2—End-welded studs were applied to tubular side rails of the docks

Fig. 3—Oak planks with predrilled holer were placed over Nelson end-welded studs during assembly

Fig. 4—Close-up of Fig. 3

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Society News

Texas Plans Extravaganza for National Fall Meeting in Dallas

The 1961 National Fall Meeting to be held September 25–28 at the Hotel Adolphus, Dallas, Tex., will be highlighted by two features—a balanced technical program of excellent and timely papers covering a wide range of applications and research projects, and Texas at its biggest and best.

Two technical papers sessions will be devoted to welding developments in the aircraft and missile field and are expected to be of wide interest to many from the southwestern portion of the country as well as elsewhere. Papers from at least three sessions will contain much useful material for engineers associated with the petroleum industry. An additional two technical papers sessions are being devoted to high strength steels and will consequently reflect the latest welding developments concerning these materials. Additional sessions relate to electron beam welding and other processes, the welding of nuclear materials, and research and weldability. A paper being presented by the Rubber Manufacturers Association will present much timely information concerning the use of hose for all types of oxygen cutting applications. (A tentative program appeared in the June issue of the WELDING JOURNAL, and a final program will be published in September.)

Texas Hospitality

The Austin Patio Ranch is to be the scene of a *Western Extravanganza* on the evening of Tuesday, Sept. 26. This promises to be an event which no AWS member will want to miss and takes the place of dinners and banquets of former years. Transportation to the ranch will be by air-conditioned bus. As AWS members, their ladies and guests arrive at the ranch gate, a posse will escort each bus to the scene of festivities. Following a sumptuous meal, entertainment is expected to consist of a western rodeo in a lighted arena under a darkened Texas sky and stars.

Unusually interesting plant tours are planned for AWS members. One tour will be a trip to Convair in Fort Worth on Sept. 26. Buses will leave Dallas about 8:30 A.M. After viewing facilities and lunching at Convair, the group will return to Dallas in the early afternoon.

Members arriving at the registration area in the Hotel Adolphus will find a message center for their use and convenience while staying in Dallas. American Airlines has arranged to fly in daily newspapers from about ten major cities during the entire week.

Ladies Program

It will be a long while before ladies of AWS members forget Dallas, beginning with a very pleasant surprise which has been arranged for those who arrive at Love

"DEEP IN THE HEART OF TEXAS" . . .

Hotel Adolphus in Dallas where 1961 AWS National Fall Meeting will be held

French Room in the Hotel Adolphus, one of several dining rooms which will prove delightful to the ladies of AWS members

A DISTRICT MEETING

Group from left to right at recent meeting of District No. 9 Executive Committee in Austin, Texas: Standing—C. R. Brownrigg, A. J. Bell, C. Matlock, F. McBee, F. Salmons, J. Collins, P. Pennypacker, J. Walker, H. Johnston, and J. Kelly; seated—J. Bergeron, Prof. Begeman, J. E. Dato, J. Carroll, E. Mai, F. J. Mooney, C. Moss, and L. Manchester

Committee members "roll up their sleeves" and get down to work under general guidance of District Director Clif Moss (standing). J. E. Dato and F. J. Mooney were on hand to represent AWS National Headquarters

Field by air. Among activities planned for the ladies are a tour of the Museum of Western Art in Fort Worth on Tuesday, Sept. 26; this is expected to include either luncheon at the Zeider Zee in Fort Worth or at the Ports O'Call in Dallas. Another noteworthy and extremely pleasant event will be held on Wednesday, Sept. 27. This will be a tour of the Wholesale Decorative Center in Dallas which will be followed by luncheon at the Statler Hilton. In the afternoon, a fashion show will be held at the Neiman-Marcus, a department store which is known throughout all Texas as well as throughout the rest of the country and Europe.

Dallas Committee

The outcome of any meeting owes its success to those who labor behind the scenes. In the case of the coming 1961 National Fall

AWS DIRECTORS-AT-LARGE

Term Expires	1962	1963	1964
	W. H. Hobart	R. B. McCauley	J. E. Dato
	F. G. Singleton	John Mikulak	A. N. Kugler
	C. B. Smith	E. F. Nippes	T. E. Jones
	J. R. Stitt	R. D. Stout	E. C. Miller

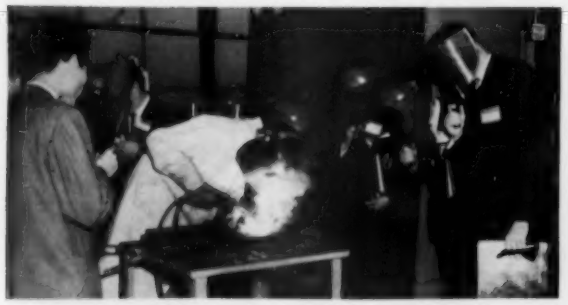
AWS DISTRICT DIRECTORS

District No. 1•New England	G. W. Kirkley	District No. 6•Central	R. H. Hoefler
District No. 2•Middle Eastern	C. L. Kreidler	District No. 7•West Central	L. L. Baugh
District No. 3•North Central	J. W. Kehoe	District No. 8•Midwest	G. O. Bland
District No. 4•Southeast	J. M. Shilstone	District No. 9•Southwest	C. L. Moss, III
District No. 5•East Central	P. J. Rieppel	District No. 10•Western	D. P. O'Connor
		District No. 11•Northwest	W. J. Ericksen

AWS PAST-PRESIDENT DIRECTORS

R. D. Thomas, Jr. C. I. MacGuffie

SPRING MEETING PLANT TOUR



Plant tours were a highlight of the recent 42nd Annual Meeting and Exhibition. Visitors saw much of unusual interest in New Jersey plants of the General Motors Corp., Worthington Corp. and the International Nickel Co. The Linde Co. Development Laboratory in Newark, N. J., was a fourth location where AWS and IIW members witnessed a variety of demonstrations involving processes such as carbon-dioxide-shielded magnetic-flux metal-arc welding shown here

Other Linde Development Laboratory demonstrations included tungsten-arc cutting, jet piercing as applied to different mineral and rock formations and single-pass J-grooving in up to 4-in. thick carbon steel plate with an oxy-fuel gas flame. Shown here is a demonstration of a new attachment for plate-edge beveling with an oxy-natural gas flame

Meeting which will be held in Dallas, many members who have already contributed much time and effort under the direction of Chairman Clif Moss are: Roy Stewart—Barbeque, Bill Irwin—Plant Visitation, Milt Eliot—Ladies Entertainment, Fred Salmons—Hospitality and Technical, Ed Mai—Meeting Sessions, R. F. Skipwith—Publicity.

Hotel Reservations

The hotel reservation forms for the Dallas meeting were mailed out from National Headquarters in mid-July. A Society spokesman urged all AWS members, who are planning to be present in Dallas, to complete their forms and return them to AWS Headquarters in New York, N. Y., to ensure accommodation.

Welcome

• Supporting Companies

Effective April 1, 1961:

Gaspro, Ltd.
Honolulu, Hawaii

Honolulu Iron Works Co.
Honolulu, Hawaii

Effective June 1, 1961:

John W. Hancock Jr. Inc.
Roanoke, Va.

General Electric Co.
Salem, Va.

Jones Welding Supplies
Roanoke, Va.

Drill Carrier Corp.
Salem, Va.

Memo to AWS Members

Plan now to be

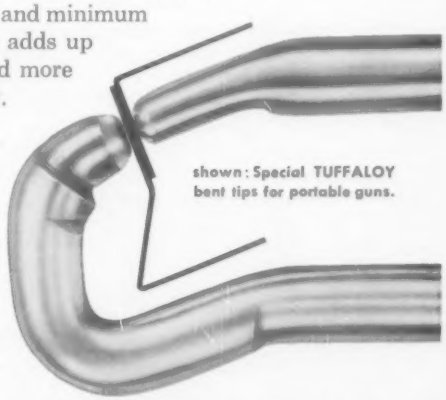
in Dallas, Texas, for

the Fall Meeting on

Sept. 25-28!!

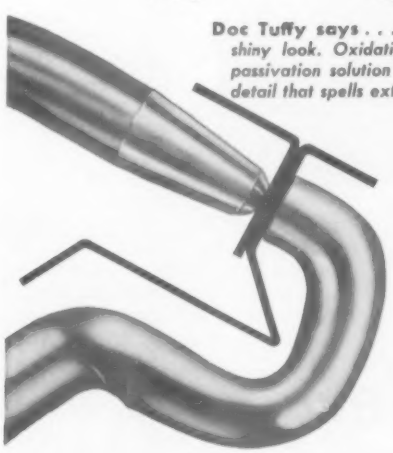
The Strongest Bent Tips Come From TUFFALOY

You get more spot welds for your money when you buy TUFFALOY bent tips. These electrodes are bent to precise angles so skillfully that there's no sacrifice of the wall strength needed to withstand heavy forging pressures. Examine a TUFFALOY bent-tip—the diameter remains constant and the coolant hole is unobstructed. So carefully is the job done that there's no cave-in at the outside of the bend, and minimum swelling at the sides. This adds up to longer electrode life, and more spot welds for your money.



shown: Special TUFFALOY bent tips for portable guns.

Doc Tuffy says . . . All TUFFALOY tips keep their bright and shiny look. Oxidation is inhibited by dipping the parts in a passivation solution . . . another example of our attention-to-detail that spells extra value for you.



Write or call your nearest AIRCO or TUFFALOY distributor for more information about TUFFALOY bent tips. Many styles are stocked as standard items, and special designs are quickly made to order. Be sure to ask for the TUFFALOY Catalog.

AIRCO

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For details, circle No. 10 on Reader Information Card

View from the Welding Journal office in the present Engineering Building located in the heart of New York's garment district

View from the new Journal office in the UEC Building shows United Nations park and the East River which borders Manhattan

Old and New

Pledges continue to move sections up the ladder to reach their goal. Fifty-five sections, on the Honor Roll, have attained 100% or more of their assigned goal. However, AMERICAN WELDING SOCIETY pledges stand at 90% of goal.

UNITED ENGINEERING CENTER

Honor Sections

Section	Goal, %	Section	Goal, %
Oklahoma City	138	Iowa	107
New Jersey	133	Niagara Frontier	107
Louisville	130	Sangamon Valley	107
Mahoning Valley	121	Maryland	106
Kansas City	120	Bridgeport	105
Worcester	120	San Antonio	105
Baton Rouge	119	Syracuse	105
Birmingham	118	Cincinnati	104
Northwest	117	Providence	104
North Texas	115	Northern N. Y.	103
Hartford	114	N. E. Tennessee	102
Wichita	113	Puget Sound	102
Philadelphia	112	Tulsa	102
Colorado	111	San Diego	101
Detroit	111	Chattanooga	100
Albuquerque	110	Eastern Illinois	100
Dayton	110	Long Beach	100
New Hampshire	110	Los Angeles	100
Pascagoula	110	Madison-Beloit	100
Richmond	110	Michiana	100
Western Mass.	110	Mobile	100
Holston Valley	109	Nashville	100
New York	109	N. Central Ohio	100
Rochester	109	Olean-Bradford	100
St. Louis	109	Salt Lake City	100
Boston	108	San Francisco	100
Long Island	108	Santa Clara Valley	100
Toledo	108		

Pledges Needed to Meet Goal

Section	Needed	Section	Needed
Pittsburgh	25	Peoria	365
Carolina	64	Susquehanna Valley	350
Anthony Wayne	150	York-Central Pa.	375
Shreveport	155	Houston	400
Iowa-Illinois	180	Sabine	400
Washington	180	Saginaw Valley	400
Arizona	200	Lehigh Valley	415
Nebraska	200	Fox Valley	450
J. A. K.	275	Portland	485
Orange County	275	Stark Central	495
Northwestern Pa.	280	Columbus	770
Indiana	312	Milwaukee	877
South Florida	330	Cleveland	900
Western Michigan	330	Chicago	1410
New Orleans	350		

KEEPING YOU POSTED

By Fred L. Plummer

● Each year your Secretary edits a general report which includes individual reports of committee and council chairmen and of district directors, in addition to a summary of activities of officers, Executive-Finance Committee and Board of Directors written by your Secretary. Copies of this report may be obtained by any AWS member who requests same by writing to national headquarters. The following consists of quotations from this 1960–61 annual report:

Our President: R. D. Thomas, Jr., in his address presented at the Annual Meeting and published in the June 1961 issue of the WELDING JOURNAL, discussed the importance and increasing value of technical cooperation between the leading countries of the world and described the expanding leadership and activities of the SOCIETY in improving such cooperation. During the entire 1960–61 fiscal year President Thomas provided inspiring leadership and sage, effective guidance.

● President Thomas presided at all meetings of the Executive-Finance Committee and the Board of Directors and attended many meetings of councils and important committees. He conducted our national meetings, speaking forcefully and with distinction on these and many other occasions. He visited all major areas of the country, meeting with more than 30 AWS sections, discussing SOCIETY activities and objectives, and presenting interesting and instructive technical talks.

● He represented the SOCIETY at the June 1960 Annual Assembly of the International Institute of Welding in Liege, Belgium, and served as host, delivering a welcoming address at the opening session, presenting assembly medals to distinguished visitors, participated in commission meetings, receptions and other social activities, during the 1961 IIW Annual Assembly, held in New York and organized by AWS.

● Top executive of an important company in the welding industry, President Thomas through outstanding leadership has made possible further expansion of SOCIETY activities and services to members, the welding industry, our country and in an increasing manner to the entire world.

Our Prime Officers: During the 1960–61 fiscal year J. H. Blankenbuehler, A. F. Chouinard and C. E. Jackson served as vice presidents and chairmen of the Districts, Technical and Publications-Promotions Councils, respectively. Each of these men, with a strong background of industrial, technical and executive experience, has given generously of his time and talents in promoting the varied successful projects and continuing activities of your SOCIETY. For the 1961–62 fiscal year, Mr. Chouinard will serve as President, J. Bland, J. H. Blankenbuehler and C. E. Jackson will serve as vice presidents and chairmen of the Publication-Promotions, Technical and District Councils respectively.

Our Past Presidents: Past President C. I. MacGuffie, as chairman of the Administrative Council, the National Nominating Committee and the Honorary Membership Committee and member of other important committees; G. O. Hoglund as chairman of Arrangements for the National Fall Meeting in Pittsburgh and as chairman or member of several committees; C. P. Sander as member of the Awards and Reserve Funds Committees; J. J. Chyle as chairman of the Sustaining Membership and member of other committees; J. H. Humber stone as chairman of Headquarters Housing Committee and responsible for the successful enlisting of industry support which made possible the organizing and conduct of the 1961 Annual Assembly of the International Institute of Welding; H. W. Pierce as member and O. B. J. Fraser as chairman of the Reserve Funds and a special Pensions Committees; all of these past presidents continue their active support and important participation.

Our Treasurer: H. E. Rockefeller has now served the SOCIETY as treasurer for four years and will continue to do so during the 1961–62 fiscal year. He has directed the preparation of balanced budget in a form so that each operating department is encouraged to carefully control all expenses and attempt to increase income. Each year under the guidance of Treasurer Rockefeller the SOCIETY has operated successfully under these budgets and has completed each year with an excess of income over expense. Each year the budget total has been increased to provide for new and expanded activities. The excess of income over expense during these years will cover moving, installations, new equipment and other expenses connected with the transfer of headquarters to the new United Engineering Center (about Sept. 1, 1961) without the use of reserve funds previously set aside for this purpose. A separate financial report gives detailed figures covering income and expenses. The Society is very much indebted to Treasurer Rockefeller for his wise counsel and guidance. At the Annual Meeting of the SOCIETY, Honorary Membership was conferred on Mr. Rockefeller.

Our Board of Directors: Thirty individuals constituted the 1960–61 Board of Directors and served as members of the Executive-Finance Committee and the four councils which act for the Board of Directors. These groups are responsible for all decisions affecting SOCIETY policies, plans, personnel and activities. Those who serve in these groups are elected by the members of the SOCIETY and are their official representatives. These men are leaders in industry and professional activities who, with the generous support of their companies, make available their wealth of experience and training as they consider SOCIETY plans and problems.

● Past President G. O. Hoglund, Directors-at-Large A. A. Holzbaur, D. B. Howard and J. L. York, and District Directors E. E. Goehringer, C. B. Robinson and H. E. Schultz completed their terms as Board Members. All of these men have faithfully and productively met their responsibility and each has contributed effectively in the planning and conduct of SOCIETY activities.

Our Sections: New AWS sections, to be known officially as the Orange County (California, near Los Angeles), Greater Huntsville (Alabama) and Southwestern Virginia (Roanoke) were established during the 1960–61 fiscal year and a group in Hawaii had met all requirements so that formation of the Hawaii

Section effective as of June 1, 1961, was requested and approved at the June 6, 1961, meeting of the 1961–62 Board of Directors.

● A special committee headed by Director C. L. Moss III and reporting to the Districts Council has developed a Section Incentive Rating Plan which will become effective during the 1961–62 fiscal year.

Our Staff: Two new members were added to the headquarters staff during the 1960–61 fiscal year, bringing the total to 38. Several important changes occurred. WELDING JOURNAL Editor B. E. Rossi and Assistant Editor Carl Willer resigned and were replaced by T. P. Schoonmaker and R. H. Chamberlin. Advertising Manager F. J. Talento and Production Manager Catherine M. O'Leary continued their loyal and productive services.

● Technical Secretary E. A. Fenton was handicapped by a complete change in the members of his staff. His two chief assistants are now N. S. Farrell and N. E. Orrok.

● Information-Education Secretary and HANDBOOK Editor A. L. Phillips has a new assistant, Frank Norton, who with W. Hall has helped broaden the activities of this group.

● W. M. Waldron now serves as Office Manager, maintaining direct contact with members and sections, supervising the collection of dues, maintaining accurate addresses, filling orders for publications and other items, coordinating the work of the duplicating and mailing departments.

● E. Krisman who became Assistant Treasurer as of June 1, 1961, has charge of the bookkeeping department, is responsible for equipment and devoted a portion of his time to convention plans and facilities. Miss S. Snyder is Head Bookkeeper.

● Assistant Secretary F. J. Mooney works directly with your Executive Secretary handling special assignments, personnel, Exposition and National Meeting activities, and devoting a major portion of his time to the promoting of new memberships and increasing services to members.

Highlights: The National Fall Meeting of the SOCIETY was held in Pittsburgh, Sept. 26 to 29, 1960. A full program of technical papers, plant tours, a conference luncheon, ladies' activities, educational, publicity and section officers conferences, and meetings of the Board of Directors, councils, committees and other groups was conducted and well attended. The American Society of Civil Engineers, the Society for Nondestructive Testing and the Column Research Council co-sponsored several of the technical sessions. Future National Fall Meetings are scheduled as follows: 1961, Dallas; 1962, Milwaukee and 1963, Boston.

● The Annual Meeting of the Society was held in New York, Apr. 17–21, 1961, with the Adams Lecture presented by H. Granjon of France, the President's Address and presentation of honors and awards by R. D. Thomas, Jr., the Educational Lecture by N. N. Rykalin of Russia, a full program of technical papers including nine by foreign representatives of the International Institute of Welding and an equal number sponsored by the American Institute of Electrical Engineers, a reception and joint AWS-IIW banquet, three full days of plant tours covering six plants, an interesting program for the ladies, meetings of the Board of Directors, councils, committees and associated groups.

● For the first time the Annual Assembly of the International Institute of Welding was held outside of Europe. This important event was held in New York in conjunction with the AWS Annual Meeting and Welding Exposition. Some 120 delegates from Europe arrived on a

A Final Last Minute Reminder

AUTHORS....

August 15, 1961, is the deadline when application forms and abstracts must be postmarked in order to receive consideration for presentation at the AWS 43rd Annual Meeting to be held in Cleveland, Ohio, April 9–13, 1962.

The application form was included as a detachable insert in the May issue of the WELDING JOURNAL. Additional copies of the application may be obtained by writing or telephoning to AWS headquarters, 33 W. 39th St., New York 18, N. Y.

chartered plane during the evening of Apr. 9, 1961. The total enrollment was in excess of 500 with some 375 coming from the 28 member countries other than the USA. President Walter Edstrom of Sweden presided at meetings of the Executive Council April 10th and the Governing Council April 11th and at the formal opening session April 12th. The 15 IIW Technical Commissions held four day sessions Apr. 12–15. A full program of social events, plant tours, sight seeing and other activities was planned and sponsored by AWS.

● The Welding Exposition was held in the New York Coliseum Apr. 18–20, 1961, and established new records for attendance (19,125) and net area of exhibit space (41,000 sq ft). Future expositions are scheduled as follows: 1962, Cleveland; 1963, Philadelphia; 1964, Detroit; 1965, Chicago; and 1966 an east coast city not yet determined. At the 1962 Annual Meeting and Welding Exposition in Cleveland the ASME will co-sponsor some technical sessions and the SNT (Society for Nondestructive Testing) will co-sponsor the exposition and hold their annual meeting in conjunction with the AWS events.

● Vice-President J. H. Blankenbuehler with the full support of President Thomas and the 11 district directors promoted the soliciting of funds to meet the AWS quota for the new United Engineering Center in which our national headquarters offices will be established about Sept. 1, 1961.

● The Board of Directors has established a new award in honor of former WELDING JOURNAL Editor W. Spraragen to be given each year for the best research paper printed during that year in the supplement of the WELDING JOURNAL.

● Several hundred AWS members now enjoy "loss of time" and "hospital-nurse-surgical" protection under the group insurance program made available to them during the 1959–60 fiscal year. Our Group Insurance Committee is now considering plans to expand the coverage made available under this program which is administered by others, without expense or income to the SOCIETY.

● The AWS School of Welding Technology conducted three courses of one week duration each and devoted to: (1) "Welding Metallurgy," (2) "Inspecting and Testing" and (3) "Welded Piping for Industrial Piping Systems."

● The Technical Department has issued the following major publications: AWS Definitions—Welding and Cutting; Master Chart of Welding Processes; Recommended Practices for Automotive Welding Design; and Fabrication of Rocket Motor Cases.

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It's important to note that the Miller conversion kits utilized to obtain any of the above simply *extend* the built-in superiority of the 300 series' welding characteristics into the type of application desired. It's adaptable by design—*not* accident.

Available in 200, 300, 400 and 600 ampere models, all feature the exclusive Miller transformers and semi-metallic rectifiers. Complete specifications, including duty cycle chart, will be sent promptly upon request.

Also available on request are two new booklets: "A Full Line of Fine Welders" and "Questions and Answers on Rectifiers for Welding."

●

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EDUCATIONAL ACTIVITIES

Welding Education

At this time of the year the new section educational chairman has just started to come to grips with the various problems. In many cases he is new to the job and, unless he gets some assistance, he is likely to find his new chairmanship a difficult assignment.

On the other hand, an experienced educational chairman will find his year of office a most enjoyable one, and one on which he can look back with the pride of achievement.

The difference between the two chairmen—the inexperienced and experienced—is largely know-how. Anxious as a chairman may be to promote education in his area, he may find it very difficult to get started unless he has someone experienced in this particular field to guide him.

This is why the Educational Activities Committee is again inviting all educational chairmen to attend the National Meeting at Dallas. An entire morning is going to be set aside to show educational chairmen the various problems they will experience and how they may be solved. It is hoped that all chairmen will attend since this is their opportunity to learn how other chairmen are making a success of section educational programs. Any who cannot attend should delegate someone from their section who is attending the Dallas meeting to sit in on this morning educational session.

Dallas

The Dallas meeting promises to be one of the best fall meetings ever held by AWS. The technical program is excellent and the Arrangements Committee is anxious to make this fall meeting an outstanding one. From reports received, the Arrangements Committee is scheduling an excellent program—especially for the ladies; it looks as though they are going to show us what Texas hospitality is really like.

We attended the Arrangements Committee meeting in May, and while there, made a point of visiting the radio and TV studios. The directors were very receptive and most interested in our technical program and in the many engineers who would be visiting Dallas during that week in September.

We are hoping to put on an hour-long educational TV show to say nothing of interviews and radio programs.

The Dallas newspapers were interested in our technical sessions and were anxious to have any news we could give them of developments in the welding industry.

Educational How-to-do-it

The Educational Open Meeting at Dallas will again follow the lines that were so successful last year in Pittsburgh. It will be a "shirt-sleeve" how-to-do-it session where the nuts and bolts of the operation are explained. We are hoping to go into basic facts, how education should be presented by sections and what is involved when an educational course is contemplated.

We are fortunate in having Professor L. Wagner of the University of Michigan with us on this occasion. He conducted one of the most successful educational series that has been held. He organized a committee, selected a subject, arranged for the instructors, found the right location, promoted the course, decided upon a textbook and finished with a highly successful course. So successful was it that he obtained 48 new members for the AMERICAN WELDING SOCIETY.

The same result can be achieved by any section with an enthusiastic committee if it follows a proper schedule, has good instructors and promotes the course correctly.

Professor Wagner has agreed to tell us of every stage he went through and every problem that had to be solved. He will actually conduct a course on how to conduct an educational course. Professor Wagner is an expert who has the training and ability to impart such knowledge in a manner which is both interesting and convincing.

Publicity Know-how

Publicity might be called applied education, or the education of a different public. From the section point of view it is not only desirable, it is highly important that the publicity chairman avail himself of every opportunity to publicize his section's activities in general, and welding in particular.

The mechanics of publicity are not difficult to learn. There is a certain know-how which is necessary and there are certain basic rules to be followed, but once these are understood it is not difficult to create publicity on a local level.

National Welded Products Month this year was a great success. We had many proclamations signed by mayors and governors. We had many displays of welded products all over the country. They appeared in public squares, in banks, in store windows and were limited only by the imagination and industry of the publicity chairman and his committee.

At the Publicity Meeting in Dallas, we intend to take the basic principles of publicity and show how they can be applied on the section level. We will show how others have publicized National Welded Products Month. We will show the various steps they have taken, how they organized their committees and the steps they took to obtain proclamations.

We will show how news releases are prepared and how a simple format can be used for most of the situations which are likely to arise.

The *Planning Manual* will be shown and its uses explained. Each of the various parts of the manual has a function and are steps to be taken—stages in the promotion of the project. The *Planning Manual* has been invaluable to publicity chairmen since it is almost a textbook on how to obtain Section publicity.

This meeting at Dallas is designed to show the new section publicity chairman the elements of publicity which he will need during his year of office. A side benefit of this will be the fact that he will have learned the rudiments of promotion which can be applied to himself, to his business and to his civic interests equally well.

All section publicity chairmen should plan to attend this meeting at Dallas and, similar to educational chairmen, if unable to attend, should see that somebody from their own section is there to take their place. In this way a report on the proceedings can be given and the various pieces of literature brought back with them on their return from the meeting.

SECTION NEWS AND EVENTS

As reported to Catherine M. O'Leary

Alabama

TECHNICAL MOVIES

Mobile—The April meeting of the *Mobile* Section was held at the State Vocational Trade School on April 18th.

After a brief business meeting and installation of officers, Leo Veal of Mobile Welding Supply and program chairman showed two movies, entitled "Arc Welding Stainless Steel" and "Manual Cutting to Shape."

California

VISIT TO "UTOPIA"

Alhambra—On Thursday, May 18th, 150 members of the *Los Angeles* Section were guests of the C. F. Braun & Co. in Alhambra, for the purpose of viewing their offices and plant facilities. The trip through the industrial Utopia was scheduled for 7:30 P.M.

Upon arrival the guests were greeted by the management and, upon signing the register, were presented with a company brochure and turned over to courteous escorts in groups of 10 to 12 persons.

The immaculate appearance of the grounds and brick building a seen from the street was a treat in itself. However, the big surprise came when the group was led below ground and found itself in a subterranean paradise, all of which is sound-proofed and air-conditioned. Walking along the main corridor one could see such things as an elaborate engineering library equipped to serve all the reference needs of engineering and technical personnel, a data-processing department with their high speed electrical computer and business machines to handle a wide variety of engineering and accounting problems, and a 175-seat auditorium with fully upholstered seats and on a par with some of the finest theaters. At the end of the corridor was a harmoniously decorated, well kept and clean company restaurant and dining rooms where 1000 people may be served at a time.

At this point, the group was shown the research center, which occupies some 30,000 sq ft, devoted to applied research in the fields of metallurgy, chemical engineering and process engineering. It includes complete chemical and metallurgical laboratories, a large test bay for bench scale work, machine shop and materials testing equipment and ten pilot plants.

From here the group was taken into the factory—ten acres under one roof and one of the largest heavy-duty fabricating shops in the country—and saw different stages in the fabrication of huge tubular heat exchangers, pressure vessels and other major chemical process apparatus for plants all over the free world.

Thanks were extended to David A. Elmer, welding engineer for the C. F. Braun Co. for arranging and making possible a fine visitation, which was enjoyed and will not be forgotten by all those who attended.

LADIES' NIGHT

Los Angeles—Installation of officers and Ladies' Night was held by the *Los Angeles* Section on June 8 at the Roger Young Auditorium. "Ladies' Night" is a night where all matters of business and formalities are dispensed with and an effort is made to repay the ladies for their generosity in relinquishing evenings for their men to attend and support section activities. Upon arrival the ladies were presented with orchids and the men with boutonniers.

Cocktail hour was from 6:30 to 7:30 P.M. at which time old friendships were renewed and new friends made. Following the cocktail hour, the members, their ladies and guests sat down to a prime rib dinner, garnished with entrainment by "The Pudgets," live puppetters and remarkably clever, followed by Mardoni and Louise, an act in which the audience participated—again very clever. Following the dinner and entertainment, the party concluded with a drawing for the many door prizes generously donated by various vendors. The party was a great success and highly enjoyed by all.

During the dinner, the newly elected officers of a fiscal year were introduced as follows: R. P. Olsen, Treasurer; Leo West, Secretary; Orville Eichman, Vice-Chairman; and Al Collin, Chairman.

SEASON FINALE IN LOS ANGELES

An accordionist, magic and puppetters highlighted entertainment at Ladies' Night of the Los Angeles Section on June 8th. Among those present were (left to right): Mr. and Mrs. D. Elmer, Mr. and Mrs. R. Hayes, Jr. and Mr. and Mrs. M. Soyars

The head table provided a touch of the "old and new" in that Chairman A. Collin thoroughly enjoyed the occasion with his successor for the coming year, O. Eichman. Shown (left to right) are: Mr. and Mrs. Eichman; Mr. and Mrs. Collin. Also included at the head table were: Mr. and Mrs. Francis McGinley and Past National President C. P. Sander

SCENE OF TOUR

Plant of Pyromet Co. which was the scene of a tour by members of the Santa Clara Valley Section on May 23rd

PLANT TOUR

San Carlos—A highly interesting and informative plant tour was made by the members of the *Santa Clara Valley* Section on the evening of May 23rd. The tour consisted of a visit to the Pyromet Co. plant in San Carlos, Calif. Company officials met the members and their guests and guided them through a modern brazing and heat-treating facilities plant.

In addition to the brazing and heat-treating equipment, the visitors were shown Pyromet's ultramodern laboratory facilities designed for conducting research and development programs and metallurgical services for industry. Included in the research type of equipment were metallographic modern polishing and etching equipment, photographic darkroom equipment, metallurgical reference library and a good deal of auxiliary equipment.

The brazing and heat-treatment equipment on exhibit included: bell-type furnaces for argon brazing, bright annealing or heat-treating; high-vacuum furnace equipment for vacuum firing, outgassing, brazing and the heat treating of metals, and a bell-type oil-sealed furnace for nitriding and for tempering at higher "draw" temperatures.

During the tour, various types of equipment were in use, and the visitors had an opportunity to observe the loading and unloading of the furnaces. Well-informed guides added materially to benefits derived from the plant visit.

After the tour, the hosts offered refreshments to their guests as a final note of graciousness, ending an enjoyable evening.

Colorado

SHOW ROOM VISIT

Denver—The last meeting of the season for the *Colorado* Section was held on May 16th at Cavaleri's Restaurant. After a very good dinner and the business portion of the program, the technical portion was a visit to the show room of the United States Welding Supply Co.

Bob Lofgren arranged a demonstration on hand-operated inert-arc cutting of aluminum and stainless steel. This was a most interesting presentation, entirely different from any other subject presented this season.

ELECTION OF OFFICERS

Denver—The *Colorado* Section announced the election of the following officers for the coming year: Chairman, S. Flohr; Vice-chairman, P. Horowitz; 2nd Vice-chairman, A. A. Lambrecht; and Secretary-Treasurer, C. B. Swift.

Illinois

LECTURE SERIES

Chicago—The fourth annual lecture series being sponsored by the *Chicago* Section will be held on Thursdays, 7–9 P.M. at the "Dome," Chicago Bridge and Iron Co., 1305 W. 105th St., Chicago. The series subject will be "Welding Processes" and will take place as follows: Sept. 21, *Manual Metal-Arc* by W. B. Blackburn; Sept. 28, *Metal Cutting* by W. K. Johnson; Oct. 5, *Brazing* by J. F. Rudy; Oct. 12 and 19, *Submerged Arc* by W. B. Root and L. J. Christensen.

Further information may be obtained from E. Hemzy, Crane Co., 4100 S. Kedzie Ave., Chicago, Ill.

Indiana

WELDING ELECTRODES

South Bend—The *Michiana* Section concluded its 1960–61 series with a most interesting talk on "Welding Electrodes" by Robert Steveling, supervisor of electrode development, A. O. Smith Corp., Milwaukee, Wis. After tracing the early history of electrode development, Mr. Steveling discussed the AWS classification of welding electrodes, citing the order in which the various types were developed and how their use has varied over the years. He listed the components of electrode coatings and showed how these were mixed to obtain the properties required in any individual classification. It was a most interesting presentation.

The dinner meeting was held on May 18th at Russ Restaurant in South Bend. A social half hour followed.

LECTURE AT MIT

Associate Professor Clyde M. Adams, Jr., of the Massachusetts Institute of Technology lecturing on welding metallurgy in series sponsored by Boston Section

Massachusetts

LECTURE SERIES

Cambridge—A very successful lecture course sponsored by the *Boston* Section as part of its educational program came to a close on March 28th. The lecturer was Dr. Clyde Adams, associate professor of metallurgy at the Massachusetts Institute of Technology where the lectures were held.

The total enrollment was 181 for the series of six lectures. The text books used in this series were: *Welding Metallurgy* by O. H. Henry, G. E. Claussen and G. E. Linnert; *Soldering Manual* and *Brazing Manual*, both published by AWS. A total of almost $800 worth of books was sold during the series.

This was the seventh consecutive lecture series conducted by the Section over a period of seven years. The series consists of four different lecture courses, which are repeated every four years as follows: first year—"The Welding Metallurgy of Mild and Low-Alloy Steels"; second year—"The Welding Metallurgy of Stainless and High-Alloy Steels"; third year—"Welding Metallurgy on Nonferrous Metals and Alloys"; and fourth year—"Engineering Design for Welding."

GOLF WINNERS

St. Louis Section Program Chairman C. Barrow is flanked by winners of the golf tournament held on June 10th—F. Koch on the left and D. Skinner to the right

The particular lecture course just completed was "Welding Metallurgy of Nonferrous Metals and Alloys" and was a repeat of the course held four years ago. Enrollment was a sellout again, as it has been for every series. Next year, the course will be "Engineering Design for Welding."

Missouri

GOLF TOURNAMENT

St. Louis—The *St. Louis* Section formally closed out the 1960–61 year with its Annual Golf Tournament which was held on June 10th. Sixty-four golfers turned out to chase the little white ball.

Two trophies were awarded—the Nooter Trophy for low gross score the Lockwood Hill Memorial Trophy for low net score on the Calloway System.

Doug Skinner of the Nooter Corp. was awarded the Nooter Trophy for a low gross score of 76. Fred Koch, also with the Nooter Corp., was awarded the Lockwood Hill Memorial Trophy for low net score of 71.

New York

STUD WELDING

Olean—The regular monthly meeting of the *Olean-Bradford* Section was held on May 16th at the Castle Restaurant in Olean, N. Y. Richard O. Blankmeyer of the Nelson Stud Welding Division of Gregory Industries, Inc., of Lorain, Ohio, was the speaker of the evening. His subject "Stud Welding Story" was very well received by the group. In his talk he gave a complete description of the equipment, applications for the process, and the history of stud welding. The keen interest in his talk was shown by the response in the question-and-answer period.

ELECTION NIGHT BANQUET

Rochester—The *Rochester* Section concluded a successful season with their Annual Election Night Banquet and Bowling Party on May 18th. A group of over 100 persons attended to welcome in the new officers, as follows: Chairman, V. J. Cimino; Vice-chairman, L. R. Haslip; Treasurer, R. Cattanach; and Secretary, B. S. Payne.

Ohio

LADIES' NIGHT

Columbus—The *Columbus* Section's Annual Ladies' Night was held at the Lincoln Lodge on May 13th with over 100 members and guests present.

DISTRICT AWARD

District Director H. E. Schultz presents Membership Trophy to Columbus Section Chairman R. S. Ryan at Annual Ladies' Night on May 13th

The newly elected officers of the Section and Perry J. Rieppel, recently elected District Director, were introduced.

A dinner, followed by dancing, was enjoyed. Dancing was interrupted occasionally to announce the winners of door prizes—providing additional entertainment for a very pleasant evening.

MAINTENANCE WELDING

Toledo—On April 19th the *Toledo* Section conducted a panel discussion on "Maintenance Welding, Cutting and Hardfacing."

A great deal of interest was created as indicated by the lengthy question-and-answer period which followed the series of short talks given by the panel members.

Members of the panel were: Ed Meincke, Linde Co.; Ray Wilcoxson, Air Reduction Sales Co.; Buell Nalley, Hobart Bros. Co.; and Russ Culbertson, Haynes Stellite Co.

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For details, circle No. 12 on Reader Information Card

GAVEL CHANGES HANDS

Philadelphia Section Chairman W. W. Wooding extends congratulations to F. W. Hussey, his successor for the 1961-62 season. The occasion was the Philadelphia Section's annual dinner on May 20th

Neil Waterbury of Owens-Illinois Glass Co. acted as moderator.

Sixty-five members and guests were present at this meeting which was held at the Toledo Yacht Club.

INSTALLATION OF OFFICERS

Toledo—On May 12th the *Toledo* Section held its annual dinner dance and installation of officers at the Toledo Edison Club.

Approximately 100 members and guests with their wives enjoyed an excellent dinner followed by dancing to the music of Al Shanks and his orchestra.

The newly elected officers are: Ben Schlatter, Chairman; John L. Wolcott, First Vice Chairman; E. J. Morrison, Second Vice Chairman; Clinton Wohlmuth, Secretary; and Harley Weide, Treasurer.

Pennsylvania

ANNUAL DINNER DANCE

Saint Davids—In a way, the annual dinner dance held by the *Philadelphia* Section was a reflection of the 1960-61 technical and panel sessions. Both were highly successful, and both set a challenging pattern for next season's section officers.

The dinner dance was held on Saturday, May 20th, in the beautiful Randor Ballroom of the Treadway Inn, Saint Davids, Pa., where 310 members, wives and guests enjoyed a cocktail hour at 6:30 P.M., dinner at 7:30 P.M., a very entertaining floor show, and then dancing until 1:00 A.M.

After dinner, Walter Wooding, chairman of the Section's highly successful past season relinquished the gavel to his successor Frank Hussey.

For a hard working, go-getting committee, it would be difficult to beat the efforts of William J. Powers, committee chairman; Donald Griffith, Thomas McKearney and Thomas Kennelly who were responsible for this year's annual dinner dance.

Rhode Island

STRUCTURAL WELDING

Providence—On May 17th, the *Providence* Section held its monthly dinner meeting at Johnson's Hummocks. The speaker at the meeting was Omer W. Blodgett of The Lincoln Electric Co.

Mr. Blodgett's subject, "Structural Welding—Tool of Continuity," dealt with multiple story buildings and welded structures. The lecture covered methods of design and construction which take advantage of weld strength with resulting savings in weld metal and reduced material costs without affecting the required design strength of the structure.

RECOGNITION FOR A PAST CHAIRMAN

Chairman-elect T. Fogarty (left) presents past chairman pin to A. Seaman at the May 17th meeting of the Providence Section. Seated is Omer Blodgett who was guest speaker for the evening

ELECTION OF OFFICERS

Providence—The *Providence* Section announces the election of the following officers for the coming season: Chairman, Fogarty; First Vice-chairman, J. Bianco; Second Vice-chairman, G. W. Oyler; Secretary, John Lees; Treasurer, James Salomon; Director of Membership, Alfred Heaton; and Technical Director—Education, Raymond Gill.

PITTSBURGH ANNUAL DINNER AND LADIES' NIGHT

The Hotel Webster Hall was the scene of festivities for Pittsburgh Section members, guests, and their ladies on April 28th. Here entertainer G. Bailey is meeting some of those present, all of whose names he remembered after his first greeting

Among those (shown left to right) are the head table were: National President A. F. Chouinard and Messrs. Marlin, Lytton and Kehoe. Others present but not shown were: National Secretary F. L. Plummer and Messrs. Nourie and Davis

ANNUAL SOCIAL IN NORTHEAST TENNESSEE

Some of the many members, wives and guests who enjoyed festivities at the Northeast Tennessee Section on May 20th

Officers and others who were present on May 20th included (left to right): National Board Member E. C. Miller, Retiring Section Chairman P. Patriarca, Chairman-elect H. B. Harlan, 1st Vice-chairman F. J. Lambert, Secretary J. J. Maginnis, and Treasurer T. R. Rutkay

Tennessee

ANNUAL SOCIAL

Knoxville—The annual social of the *Northeast Tennessee* Section, held on May 20th at the Deane Hill Country Club, was a tremendous success. About a half dozen Knoxville welding suppliers were, in part, responsible for the happy carefree atmosphere that prevailed among those attending by sponsoring a most elaborate cocktail hour.

Outgoing Chairman Pete Patriarca reviewed the accomplishments of the past year and introduced E. C. Miller who presented the Chairman's pin to Mr. Patriarca and also introduced the officers for the coming season starting with the Treasurer, Lonnie Morries; Secretary, Jim Maginnis; 2nd Vice-chairman, Tom C. Dempster; 1st Vice-chairman, Frank J. Lambert, Jr.; and finally the new Chairman, Hubert B. Harlan. Chairman Harlan immediately took control of after-dinner activities and called for a more concentrated effort on the task confronting the gathering—namely, more dancing and more cocktails.

Texas

MEMBERSHIP DRIVE

San Antonio—On May 19th the *San Antonio* Section opened its 1961–62 membership drive with a Social at the Lone Star Brewery. This meeting was attended by 302 members and guests with their ladies. The film, "African Safari," was shown. This film, besides being exciting to the viewers, consisted of actual pictures taken by two prominent local citizens on a safari.

The Section held its last meeting of the fiscal year at Capt. Jim's with 44 members and guests present. Fred W. Smith, Jr., retiring chairman, presided. A short installation service was conducted for those newly elected officers and directors who will lead the Section's activities for the ensuing year. Arthur J. Bell was installed as Chairman; Charles R. Brownrigg as Secretary and E. E. Wagner as Treasurer. New Directors are: Joseph G. Cole, Erwin Heimer, Henry P. Powell, William M. Trcka, Jim C. Warren and William H. Wood.

Frank W. Davis, member of the Atomic Energy Commission and chairman of the Atomic Energy Commission Welding Forum at Southwest Research Institute, San Antonio, was the speaker of the evening, with his topic being "Weld Problems in the Nuclear Field." Mr. Davis presented a very interesting talk on the progress of atomic energy through welding processes and stated the AMERICAN WELDING SOCIETY has been most useful to the Commission by helping solve problems as they arise. Mr. Davis served two years as chairman of the Boston Section and was district vice president of the New York–New England District. The San Antonio Section is most fortunate to have a man of this standing included in its membership.

A PROCLAMATION AND TELEVISION

Mayor Clarence Mitchell of Appleton, Wis., signs proclammation designating April at National Welded Products Month. Fox Valley Section members with Mayor Mitchell are (left to right): J. G. Waldron, A. Tucker, G. Jacklin, J. Teigen and K. Loos

Technicians from Station WBAY-TV film portion of a talk by K. F. McKenzie who was guest speaker at the Fox Valley Section regular April meeting. More than 60,000 people later saw this film on TV

New Members

EFFECTIVE JUNE 1, 1961

MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

TOTAL NATIONAL MEMBERSHIP

Sustaining Members	204
Members	6,531
Associate Members	5,753
Students	362
Honorary Members	11
Life Members	32
Total	12,893

ALBUQUERQUE
Bengel, William R. (C)

BATON ROUGE
Hoffman, Paul R. (B)

BOSTON
Bates, H. Fletcher (B)
Domaingue, George H., Jr. (C)
Hood, Calvin B. (B)
Leon, Arthur J. (C)
Lombardo, John R. (B)
Thompson, Allen J. (B)
Tibbetts, Stuart A. (B)

BRIDGEPORT
McCue, William D. (B)

CANADA
Campbell, Alexander J. (C)
Lloyd, Wilfred (B)
Sugimoto, Atsushi (B)

CAROLINA
Upchurch, Thurman H. (D)

CHICAGO
Barrett, John E. (B)
Bishop, Dorman W. (C)
Collins, Thomas S. (C)
Geyer, Walter G. (B)
Salvatore, Robert J. (C)
Sternberg, Mark (B)

CLEVELAND
Janosko, Michael J. (B)
Katz, Lewis (B)
Myers, L. W. (D)

COLORADO
Clark, Ralph F. (B)
McKenzie, Hugh M. (B)
Richter, Howard J. (B)

COLUMBUS
Gwin, Richard B. (D)

DAYTON
Koenigsberg, Harry (B)

HARTFORD
Pierczyk, Andrew M. (C)
Smith, Walter M. (B)
Solomita, Rocco (B)

HAWAII
Lee, Henry T. (C)
Lufkin, Horace E. (B)
Oka, Charles T. (B)
Paresa, Manuel O. (B)
Townsend, George (C)
Townsend, William K. (B)

HOUSTON
Cotten, William C., Jr. (B)

INDIANA
Eaton, Keller (C)
Lerman, Alvin J. (C)
Prager, Samuel M. (C)

J. A. K.
Dufour, Victor Edward (D)
Godwin, Ernest (C)
Smith, Robert W. (B)
Webb, Arthur A. (B)

KANSAS CITY
Ellis, Gene L. (C)

LONG ISLAND
Bartlett, Andrew (C)
Brodwin, Bernard (C)
Dellaria, Sal (B)
Galagaran, Robert (C)
Ingarozza, J. (C)
Morra, Dan (C)
Percy, Richard A. (C)

LOS ANGELES
Monning, John C. (A)

MAHONING VALLEY
Courey, Albert J. (B)
Flinn, Martin J. (B)
Sommers, Edgar (B)

MARYLAND
Carroll, Walter E. (B)
Smith, George J. (B)

MICHIANA
Henderson, Don (B)

MILWAUKEE
Doerr, John T. (C)

NEW JERSEY
Blevins, Paul G. (C)
Krueger, Robert C. (C)
Laune, Bent (B)
Lyness, Thomas (B)
Moody, W. Albert, Jr. (B)
Nixon, William G. (B)
Sire, Bernard W. (B)
Stieve, Theodore J. (B)

NEW YORK
Adolff, Alfred P. (B)
Baer, Leo (C)
Belliveau, Normand (C)
Cohen, Edward (B)
Gendron, George J. (B)
Shanley, Frank (B)
Watson, Theodore S., Jr. (C)
Weissman, Herbert (C)
Wishnie, Frederick T. (C)

NIAGARA FRONTIER
Esposito, John M. (B)

NORTH TEXAS
Glazener, William King (B)
Wilson, Herbert C. (B)

NORTHERN NEW YORK
Mason, William R., Jr. (C)

NORTHWEST
Allard, John J. (B)
Behringer, Cecil R. (B)
Cohen, David D. (B)
Hiber, Edward C. (B)
Svec, Felix (C)
Thorness, R. B. (B)

NORTHWESTERN PA.
Altman, James Lloyd (B)

ORANGE COUNTY
McKenney, T. S. (B)

PASCAGOULA
Mayo, F. J. (A)

PHILADELPHIA
Burmeister, Harold L., Jr. (B)
Mooney, J. T. (B)
Roberts, E. V. (B)
Snell, William A. (C)

PITTSBURGH
Bessen, Irwin I. (B)
Bronchain, Charles L. (B)
Callen, Edward E. (B)
Gibson, Robert L. (B)
Lange, Hans Walter (B)
Loughran, James S. (B)

PORTLAND
Dykstra, David Gail (C)
Wills, Kenneth (B)

PROVIDENCE
Binns, Frank E. (B)
Fontes, Gilbert J. (B)
Jutras, William F. (B)

RICHMOND
McCants, Thomas H. (B)

ROCHESTER
Galloway, William S., Jr. (C)

ST. LOUIS
Kabo, Albert E. (C)

SALT LAKE CITY
Hollingsworth, Hal (D)

SAN ANTONIO
De Winne, Ernie (C)

SAN DIEGO
Rush, Bill L. (B)

SAN FRANCISCO
Nichols, Robert L. (B)
Wiggins, Arthur R. (B)

SANGAMON VALLEY
Fischer, George T. (C)

SANTA CLARA VALLEY
Skinner, P. J. (B)

SHREVEPORT
Wadsworth, William L. (B)
Williams, F. Riley (C)

SOUTH FLORIDA
Kear, George H. (B)

SOUTHWESTERN VA.
Ayers, Everett (C)
Bryant, Earle S. (C)
Butt, Bernard (C)
Conner, W. A. F. (C)
Croote, R. (B)
Cundiff, Winfred K. (C)
Dickinson, Charles W. (C)
Dixon, R. H. (C)
Furrow, Roy E. (B)
Gaybee, H. Hunter, Jr. (B)
Gibson, Hubert C. (B)
Givens, Ralph L. (C)
Hambrick, Alfred J. (B)
Henninger, Robert L. (C)
Howard, James C. (B)
Hughes, Edward J. (B)
Humphreys, Harden G., Jr. (B)
Kelly, Paul L. (B)
Larson, Paul J. (B)
Lloyd, Dean S. (C)
McLaren, W. (B)
McQuarry, W. Eugene (B)
McQuarry, Richard D. (B)
Milliken, George M., Jr. (B)
Morris, S. (C)
Murray, Thomas W. (C)
Myers, Herndon H. (C)
Noell, R. L. (C)
Oliver, Shirley (B)
Owen, Walter D. (C)

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Plunkett, Jairus (C)
Reynolds, Carl L. (B)
Riley, John (C)
Rose, W. E. (B)
Rule, Robert L. (B)
Seay, George A., Jr. (C)
Shaw, George W. (B)
Sheehan, Charles R. (B)
Smith, R. E. (B)
Stanley, Harry L. (B)
Wakeman, T. J. (C)
Webb, John, Jr. (C)

SOUTHWESTERN VA.

Wells, Lewin A. (B)
Williams, Gerald A. (B)

STARK CENTRAL

Davis, William A. (C)
Larson, John W., Jr. (C)

TOLEDO

Gass, John R. (C)

TULSA

Durnal, Chester W. (C)
Sexson, James Charles (C)
Vinyard, Daniel F. (C)
Wamsley, Jack L. (C)

WASHINGTON, D. C.

Fuller, Geoffrey Herbert (B)

MEMBERS NOT IN SECTIONS

Erikson, Stig-Erik (B)
Goodrich, Duane L. (B)
Hart, Jan (B)
Hodgkinson, John (B)
Kunze, Gunther Paul (B)
Lagasse, P. E. (B)
Poncin, Pierre (B)
Schwab, Francis C., Jr. (B)

Reclassification During June 1961

ALBUQUERQUE

Elliott, Troy H. (C to B)

J. A. K.

Getz, Roland Lester (C to B)

INDIANA

Bowers, Gerald V. (C to B)

LOS ANGELES

Kraus, William P. (C to B)
Waldron, Stephen (D to C)

MARYLAND

Canitz, Charles, Jr. (C to B)

NEW YORK

Rockefeller, Harry E. (A to E)

NORTHERN NEW YORK

Cuturilo, John (C to B)

PHILADELPHIA

Roach, Thomas A., Jr. (C to B)
Thomas, R. David, Jr. (B to F)

ROCHESTER

Stoler, Harry (C to B)

SAN DIEGO

Dyson, Elston G. (C to B)

SAN FRANCISCO

Evans, William L. (D to B)

SANTA CLARA VALLEY

Fulton, Thomas I. (D to C)

SOUTHWESTERN VA.

Jones, Reid, Jr. (C to B)
Lochner, Roy G. (C to B)

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NEWS of the industry

Alloy Rods Wins Award

A Certificate of Special Merit was awarded to the Alloy Rods Co. by the New York Employing Printers Association for the outstanding quality of printing and photography in its 20th anniversary book entitled, "A Contribution to Welding." Designed and produced by C. W. Pilkey, manager of advertising and sales promotion for Alloy Rods, the 36-page book introduces the management, facilities and personnel of this York, Pa., producer of arc-welding electrodes and hard surfacing materials. The award was made at the 19th Exhibition of Printing at the Hotel Commodore, New York City.

ASTM Presents Gillett Lecture

Augustus B. Kinzel AWS vice-president, research, Union Carbide Corp., presented the annual Gillett Memorial Lecture June 27, at the 64th Annual Meeting of the American Society for Testing Materials, Chalfonte-Haddon Hall, Atlantic City, N. J. This lecture, jointly sponsored by the American Society for Testing Materials and the Battelle Memorial Institute, commemorated Horace W. Gillett, one of America's leading metallurgists and the first director of Battelle Memorial Institute.

The lecturer considered the why, how and finality of specifications. He included a brief discussion of the nature, history, purpose and use of specifications. Topics explored included: the structure and content of specifications in relation to their objectives; the need for flexibility and judgment as a substitute for ignorance; and the relation of tests and testing to specifications, together with the effect of the nature of the test on the nature of the specification.

One of the country's leading research metallurgists, Dr. Kinzel pioneered in the theory of stainless steel and the theory and application of the structural low-alloy steels and new ferro-alloys. He is responsible for major advances in the welding and cutting of steel. In addition, he spearheaded the research that led to the development of Union Carbide's process for making titanium metal. More than 40 patents have been issued in his name.

Ampco Appoints Distributor

D & R Welding Supply Co., Decatur, Ill., was recently appointed a distributor of Ampco weldrod products by Ampco Metal, Inc.

Effective immediately, the new distributor will supply the Decatur sales area with bronze welding electrodes, bare filler rods and wire in spooled and coiled forms.

Airco Purchases Speer Carbon

Air Reduction Co., Inc. and Speer Carbon Co., subject to approval by Speer stockholders, have agreed to the acquisition by Air Reduction of Speer's assets and business in exchange for Air Reduction common stock at the rate of one share of Air Reduction stock for each 2.25 shares of Speer Carbon stock, according to a recent joint announcement by John A. Hill, Airco president and Andrew Kaul III, Speer Carbon Board chairman.

Speer Carbon, whose sales were reported at approximately $25 million for 1960, produces carbon and graphite products, as well as products used in the electronics industry such as resistors, coils, capacitors, packaged assembly components and printed circuit assemblies.

Speer Carbon will continue following acquisition at its headquarters in St. Mary's, Pa., under the present management.

PLANNING FOR MAINTENANCE SHOW

Committee headed by Show Mana er R. E. Zimmerman (kneeling), which met to consider plans for the 3rd Annual Southeastern Show to be held at the Greenboro (N. C.) War Memorial Coliseum, September 12-14. A section of the show devoted to welding is expected to draw wide attention

Lincoln Offers to Assist Adult Welding Education

The Lincoln Electric Co., Cleveland, Ohio, as part of a program to expand the use of welding through education, is entering its sixth year of helping Vo-Ag teachers instruct local adults in the art of maintenance and repair arc welding. Mr. Erik Madsen, director of rural eduction at Lincoln, states that this assistance has been requested and received during the

past five years by over 4000 schools from coast to coast. More than 70,000 adults have participated in this program that provides practical welding instruction.

The assistance, extended on a non-commercial basis, offers everything needed to conduct a "Short Course for Adults in Farm Arc Welding." Any teachers interested in the program should address their correspondence to Mr. Erik Madsen, c/o The Lincoln Electric Co., Cleveland 17, Ohio.

Science Fair Winners Tour NCG Facilities

Two winners in the 1961 Chicago public school science fair were given a tour of plant and research facilities of the NCG Div. of Chemetron Corp. in Chicago Ill., as an award

for the exhibit they combined to produce.

Roger Chorney, 17, and Anthony Mullozzi, 17, both students at Chicago's Wells High School, won the tour with their exhibit of an ion exchange fuel cell.

"Because of today's need for cheaper and more efficient power, the fuel cell has increased in importance," the young scientists explained. "We will see an even greater demand for these cells as time progresses because of our nation's need for conserving source of power such as gas, oil and coal."

The boys toured a NCG air separation plant in Chicago where liquid oxygen, nitrogen and argon are produced, and the Division's research facility at 1200 N. Claremont St.

Smith Welding Changes Name

Smith Welding Equipment Corp., Minneapolis, has a new corporate name, and has opened a new division. A change in officers occurred in May.

Smith Welding Equipment will become a division of Tescom Corp., as will a new Fluid Systems Div., informally activated January 1st of this year.

Smith now becomes honorary chairman of the board. New board chairman will be L. L. McBurney, who steps up from the presidency of Smith. Moving into the top management spot as the new president of Tescom Corp. will be Jack E. Smith, formerly executive vice-president. G. C. Swenson will be secretary.

Ampco Selects Pump Distributors

Four firms in separate industrial areas of the country have been named by Ampco Metal, Inc., Milwaukee, Wis., as distributors of its line of pumps designed to move corrosive materials.

The new distributors are: R. S. Brookman Associates, Buffalo, N.Y.; Mesco, Inc., Chicago Heights, Ill.; Power Plant Engineering Co. Syracuse, N. Y.; W. L. Somner Co., Inc., Shreveport, La.

General Dynamics Creates Five New Divisions

General Dynamics Corp. recently announced the creation of five new operating divisions, two major organizational groups and a realignment of corporate executive responsibility.

The new divisions, all formerly components of the Convair Div., are: General Dynamics/Astronautics, General Dynamics/Fort Worth, General Dynamics/Pomona, General Dynamics/San Diego and General Dynamics/Daingerfield.

The former Convair General Office at San Diego, Calif., will be eliminated. Key personnel will be reassigned to the corporate staff or to operating divisions.

Sylvania Parts Opens New Weld Plant

A new plant for the production of welded components for the electrical-electronics industry was formally opened here today by the Parts Div. of Sylvania Electric Products, Inc., a subsidiary of General Telephone & Electronics Corp.

Because the new building and its manufacturing equipment "are the most modern in existence, designed specifically for weld production," according to Merle W. Kremer, vice president and general manager of the Parts Div., "it has been possible to confine this complex operation to a building containing only 20,000-sq ft of manufacturing and associated space."

COMING EVENTS

A Calendar of Welding Activity

AWS

Sept. 25–28. 1961 National Fall Meeting, Hotel Adolphus, Dallas, Tex.

AEC

Sept. 20–22. Welding Forum—Annual Meeting (classified), Granada Hotel, San Antonio, Tex.

AIPE

Sept. 12–14. Third Annual Southeastern Show. Greensboro War Memorial Coliseum, Greensboro, N. C.

ASM

Oct. 23–27. Detroit Metal Show (43rd National Metal Congress and Exposition), Cobo Hall, Detroit, Mich.

ISA

Sept. 6–8. Joint Nuclear Instrumentation Symposium, North Carolina State College, Raleigh, N. C.

Sept. 11–15. Fall Instrument—Automation Conference and Exhibit and 16th Annual Meeting, The Biltmore Hotel and Memorial Sports Arena, Los Angeles, Calif.

SES

Sept. 18–20. Tenth Annual Meeting. Hotel Sherman, Chicago, Ill.

Alloy Rods Appoints Two Distributors

Hopper Machine Works, Bakersfield, Calif. and Tennessee Welding Supply Co., 914 Sevier Ave., Knoxville, Tenn., have been appointed as distributors for the full line of Alloy Rods Co. products, it was announced by E. R. Walsh III, sales vice president for this York, Pa., manufacturer of alloy arc welding electrodes and hard surfacing materials.

A. O. Smith Moves Sales Office

A recent West Coast sales office location change has been announced by A. O. Smith Corp. Regional sales headquarters for the firm's Welding Products Div. and Electric Motor Div., formerly in Newark, Calif., have been moved to the Pacific Building, 610-16th St., in Oakland.

A. R. Schneller heads the Welding Products Division headquarters. Electric Motor Div. district manager is W. A. Joubert.

Graver Tank Forms New Department

Robert W. Johnson, vice president for marketing and sales, Graver Tank & Mfg. Co., Division of Union Tank Car Co., has announced the formation of a new product planning department.

Manager of new product planning is Joseph J. Finnegan. Prior to joining Graver Tank, he was with a Chicago-based investment company.

Los Angeles Group Acquires Fabriform Metal Brazing

A group of Los Angeles businessmen headed by A. M. Thompson, recently formed a corporation and purchased the assets of Fabriform Metal Brazing, Los Angeles metal joining company, from the George Getz Corp., Chicago, Ill.

With A. M. Thompson as president, the new corporation will be known as Fabriform Metal Brazing, Inc., and will continue operations from its present location at 7720 Maie Ave., Los Angeles. Thompson, who has been General Manager of Fabriform for a number of years, stated that the company does not contemplate any changes in its present operation.

Linde Flame-Plating Plant in Production

A new plant for applying flame-plated coatings is in full production at North Haven, Conn. According to W. B. Nicholson, president of Linde Co., Division of Union Carbide Corp., the plant was built by Linde to help meet the rapidly growing demand for their unique coatings by East Coast industries.

After choosing the site on Sackett Point Rd in North Haven, Linde broke ground for the plant a year ago May and started construction during the following three months. The location was selected with the cooperation of the Connecticut Development Commission and the Area Development Office of the United Illuminating Co. It is adjacent to Linde's North Haven gas plant which handles oxygen and acetylene needed for the process as well as other industrial gases for the area.

Metalock Agency Appointed

Metalock International, Inc., Long Island City, N. Y., announced the appointment of Metalock Co. of Mich., Inc., 5453 E. Davison, Detroit 12, Mich., as the authorized Metalock agency for that area for the Metalock Cold Repair Process.

Cold repairs performed by specially trained and licensed service personnel, utilizing Metalock keys, Masterlocks and Metalace, will reportedly solve a wide range of repair problems on cracked or broken machinery and equipment parts.

Bren/Weld Forms New Sales Unit

Bren/Weld Corp., Brooklyn, N. Y., recently announced the formation of Bren/Weld Sales, Inc., to handle all sales, promotion and advertising of the firm's line of welding equipment. Ingram Carner is president of the new corporation and Nathan N. Zell has been retained as sales development consultant. Walter J. Zimmerman Associates, Inc., has been appointed advertising agency.

Nondestructive Test Courses Continue at Magnaflux

The Magnaflux Corp., Chicago, Ill., has announced that 5-day courses in nondestructive testing are scheduled to begin on Aug. 14 Sept. 14, Oct. 16, Nov. 13 and Dec. 4.

Classes are limited to eight men—usually supervisors of quality, inspectors, metallurgists, operators and those responsible for training operators. The courses are also under the direction of B. D. Tyler. Attendance is by prior registration only, and details may be obtained by contacting the Magnaflux Corp., 7300 W. Lawrence Ave., Chicago 31, Ill.

NCG Distributor Has 30th Anniversary

A supplier of industrial and medical gases and equipment to a six-county region surrounding Mansfield, Ill., recently celebrated its 30th anniversary as a distributor. Mansfield Oxygen Co., a distributor for the National Cylinder Gas Div. of Chemetron Corp., began operations early in 1931 as a section of a hardware store, and was known as Mansfield Cylinder Gas Co., according to the owner, Edward O. Delp. The business was moved to its present address in 1947.

Webb Pump Named NCG Dealer

Webb Pump and Supply, Inc., Escondido, Calif., has been appointed a dealer for the National Cylinder Gas Div. of Chemetron Corp., a major producer of medical and industrial gases, medical apparatus, and welding and cutting equipment, the two companies announced.

Arthur Means, president of Webb Pump and Supply, said his company

ADULT EDUCATION IN FARM WELDING

Lincoln Electric Co. assistance to vocational-agricultural teachers in conducting "Short Course for Adults in Farm Arc Welding"

would handle the full line of NCG products for distribution in northern San Diego County. Webb Pump has branch dealers at Fallbrook Vista and Oceanside.

Norelco Analytical School in San Francisco

The 40th Norelco X-ray Analytical School will be held at the Sir Francis Drake Hotel, San Francisco, during the week of Sept. 11–15, 1961, according to an announcement by Philips Electronic Instruments, Mount Vernon, N. Y.

Registration for the course, which will cover X-ray diffraction, diffractometry and spectrography, is open to chemists, metallurgists, physicists, production supervisors, qnality control engineers and others interested in the application of these techniques.

There is no charge for attendance but capacity is limited. Those who plan to attend should notify the company as soon as possible.

Linde Begins Cryogenic Expansion

Linde Co., Div. of Union Carbide Corp., recently revealed plans for a $2.5-million expansion and modernization of its manufacturing facilities at East Park Dr. and Woodward Ave. in Tonawanda, N. Y. Expressing Linde's confidence in the continuing growth of the cryogenic equipment business, president William B. Nicholson pointed out that capital investment in equipment for oxygen, nitrogen and argon production averaged about $40 million per year in the decade of the '50's, and is expected to reach the $100 million per year level during the '60's.

Expansion plans for the Tonawanda plant include the construction of a new manufacturing building of approximately 60,000 sq ft, and metal-cleaning facilities of about 11,000 sq ft. The new facilities will be devoted to the construction of on-site oxygen, nitrogen and hydrogen plants, to the production of the company's own central producing mass liquid plants and to the fabrication of equipment utilized in the storage, distribution and use of liquefied gases supplied by a network of central plants.

In all, the addition of these facilities will provide an increase of approximately 20% in the Tonawanda factory's productive capacity. Full utilization of the new facilities will eventually require about 150 additional personnel. Completion of the expansion and modernization work is scheduled for mid-1962.

New General Dynamics Facility Planned

A new metallurgical development and fabrication center will be constructed in San Diego, Calif., by General Atomic Div. of General Dynamics Corp. The new center, to be completed in early 1962 on a 28-acre site in Sorrento Valley, Calif., will be adjacent to General Atomic's John Jay Hopkins Laboratory for Pure and Applied Science.

Dr. Frederic de Hoffmann, senior vice president of General Dynamics and president of General Atomic Div., said the 52,000-sq ft facility will be devoted largely to development and fabrication of fuel elements for General Atomic's advanced nuclear reactor systems for central station power generation and for propulson, as well as for General Dynamics' TRIGA reactors for research, training and testing.

When fully equipped, the center will represent an investment of about $2 million.

Picker X-Ray Announces New Division

A new division to design and produce individualized nondestructive testing systems for industry has been formed by Picker X-Ray Corp., White Plains, N. Y., Harvey Picker, president, announced recently.

Donald T. Green, chief industrial applications engineer for Picker, was named manager of the Special Products Div., which

45-YEAR VETERANS

Special executive banquet and presentation of watches recently commemorated 45-year service anniversaries for two departmental supervisors of Harnischfeger Corp., Milwaukee. President Henry Harnischfeger, center, congratulates Walter Meitner, left, repair parts costs supervisor and John Farley, right, central engineering division supervisor

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Here is your biggest opportunity in 10 years to sell welding equipment to 16,000 top foundrymen — 3 out of 4 with the power to specify. Display your wares and tell your story with a booth at

THE BIGGEST FOUNDRY EXPOSITION IN 10 YEARS

66th CASTINGS CONGRESS and EXPOSITION

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29th INTERNATIONAL FOUNDRY CONGRESS

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For details, circle No. 15 on Reader Information Card

will be located in Cleveland where the company has its research and manufacturing facilities.

Lincoln Holds Welding Supply Dealer's Meetings

650 welding supply dealers attended 70 meetings held across the nation by The Lincoln Electric Co. Cleveland, Ohio.

Thse meetings were concentrated into a three day period to quickly introduce Lincoln's national organization to a new design AC-225-S welder that, the company claims,

holds particular importance for those persons trying to reduce costs in maintenance and small shop fabrication. Lincoln states the new machine fills the need for a lower price welder that can weld jobs previously requiring larger, higher priced industrial machines. The meetings were held in Lincoln's district offices located in 35 major industrial areas in all sections of the country.

Liquid Cutting

The first production model of a "liquid lathe" for cutting materials was recently demonstrated at Navan Products, Inc., sub. of North American Aviation, Inc., El Segundo, Calif., before industry and military representatives.

The liquid lathe, a machine which resembles a cannon, delivered a needle point of liquid under thousands of pounds of pressure, cutting through cement, wood and tough plastic in the display of its capabilities.

The liquid cutting concept was invented in the Los Angeles Div. of North American Aviation as part of research sponsored several years ago by the company to find tools and processes for shaping and forming exotic materials for advanced aerospace craft.

An immediate practical market for the concept was found in the safe removal of high energy solid propellant materials from engine casings.

The liquid lathe was developed and manufactured by Abrasi-Jet Machine Tool Corp., Glendale, Calif., under license from Navan, North American's invention marketing subsidiary, and is designed especially for cutting solid propellant materials.

According to Joseph N. Kearney, Abrasi-Jet president, models for cutting and shaping metals and other materials are also being developed.

Wright Aeronautics Joins in Metals Study

The Wright Aeronautics Div. of the Curtiss-Wright Corp. recently became a member of a team of nationally-known industrial firms in an extensive study to determine the causes of wear and friction in metals, according to the Armour Research Foundation of Illinois Institute of Technology.

Initiated a year ago with 10 industrial sponsors, ARF researchers on the program are seeking the answers to the age-old mysteries surrounding the wear and friction properties of metals.

The other companies taking part in the three-year, $300,000 program are American Steel Foundries, Bethlehem Steel Co., Briggs and Stratton Corp., Clevite Corp., Dow Chemical Co., Inland Steel Co., International Harvester Co., International Nickel Co., Socony-Mobil Oil Co. and the United States Steel Corp.

Kolestan Opens New Liquid Argon Unit

A modern liquid argon installation with a capacity of 100,000 cu ft of argon went into service recently at Kollstan Semiconductor Elements, Div. of Kollsman Instrument Corp. in Golden, Colo.

Designed and installed by Linde Co., Div. of Union Carbide Corp., the new unit stores liquid argon at about −300° F, and automatically converts it to a gas on demand. Kollstan utilizes the inert characteristics of gaseous argon in the manufacture of crystal element subassemblies for transistors, diodes and other semiconductor devices.

United Welders Forms New Division

United Welders, Inc., Bay City, Mich., recently announced the formation of a new division, United Machines and Engineering, Inc., in Fort Smith, Ark. The new division will specialize in design and fabrication of equipment for: handling and transfer of in-process workpieces, plastics part manufacturing, application of chemical-foam insulation and special machining operations.

Harnischfeger Mid-Year Report

Despite tighter markets and more aggressive competition for all five of its major product lines, Harnischfeger Corp. of Milwaukee finished the first half of the 1961 fiscal year with slightly better sales volume than for the similar period last year.

According to an interim report, sales of "P&H" products for the six months ending April 30 stood at $39,665,152 for an increase of $247,276 over the $39,417,876 sales mark for the first six months last year.

Net earnings after taxes for the same 1961 period were $595,299 or 1.5% of sales, which was a decrease of $261,967 from the 1960 mid-year net of $857,266 or 2.2% of sales.

Nelson Composite Beam Patent Awarded

Gregory Industries, Inc., was recently granted a patent by the U. S. Patent Office on the Nelson Composite Beam, a stud-welded framing element developed in the middle '50's to improve the efficiency and lower the cost of composite steel and concrete bridge and building construction.

The patent was issued in the names of Robert C. Singleton, now vice president in charge of engineering of Gregory Industries, and Richard E. McGinnis, now its vice president in charge of sales. It relates to a steel and concrete composite construction wherein studs are end welded on a metal beam or other base and used as shear connectors to cause the beam or other base and the con-

For details, circle No. 16 on Reader Information Card ——>

World's newest engineering center welded with M&T Murex electrodes

On October 1, 1959, ground was broken for the new all-welded United Engineering Center on New York's United Nation's Plaza. Scheduled for completion in late 1961, the building is 18 stories high, contains 179,855 sq. ft. of space. Construction consumed 15 tons of electrodes. In erecting the steel for this Engineering Center, the engineers of Dreier Structural Steel Company put their trust in Murex electrodes—products of METAL & THERMIT CORPORATION, General Offices: Rahway, N. J.

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crete slab to act as a unit.

This technique has been used in a total of more than 3000 highway bridges and scores of buildings of various types since the first stud-welded composite bridge was opened at Pierre, S. D., just five years ago.

Railroads Eliminate Clickety-Clack

U. S. railroads are rapidly becoming smoother and quieter—and saving money thereby.

Railroad companies are reported to be stepping up the installation of continuous welded rail which reduces the number of conventional bolted joints with their "clickety-clack" gaps between the rails that cause damage to rolling stock and freight amounting to millions of dollars annually.

More than 1200 miles of welded rail were laid in 1960—13 times as much as in 1954—according to the NCG Division of Chemetron Corp. which reportedly produces more than 40% of the rail welded in this country.

"In the last five years 3800 miles of welded rail were installed in the U. S. This will save the railroads more than $3,800,000 annually," said Robert A. Baer, head of NCG rail welding operations.

Welded rail reduces costs by about $1000 per mile each year in addition to the damage savings, according to surveys by the American Railway Engineering Assn., as it lasts longer and costs less to maintain than conventional bolted rail. Regular 39-ft lengths are joined, often in quarter-mile lengths, by welding joints which are said to be as strong as the rail itself.

Bauer said introduction of the electric flash process, which squeezes rail ends together under tremendous heat and pressure, is in large part responsible for the increase in welded rail installation as it is two to three times faster than other methods. More than three quarters of the continuous rail produced today is welded by this process, he said.

Elgin Abrasives Names Six Wheel Distributors

The Abrasives Division of the Elgin National Watch Co. has announced the appointment of the following six companies as distributors for the Division's Diamond Wheel Products: Baldwin—Hall Co., Inc., Potsdam, N. Y.; Baldwin—Hall Co., Inc. Syracuse, N. Y.; George V. Morris, Philadelphia, Pa.; Quad Tool and Die Supply, Merchantville, N. J.; Tool and Abrasives Engineering Co., San Jose, Calif.; and Tool Mart, Inc., Van Nuys, Calif.

Whitehead Metals Opens New Sales Office

A new sales office and warehouse was opened in Baltimore, recently by Whitehead Metals, Inc. Located in Meadows Industrial Park at Woodlawn, the new building has 30,000 sq ft of warehouse area and 4000 sq ft of office space. It permits Whitehead Metals, a subsidiary of The International Nickel Co., Inc., to increase its service to industry by expanding its inventories of corrosion-resistant metals for prompt delivery in Maryland, the District of Columbia and Virginia. The company stocks plastics, and welding and brazing materials in addition to sheet, rod, pipe, tubing, wire, valves, fastenings, wire mesh, shot and ingots in nickel, high nickel alloys, aluminum, copper, brass and nickel stainless steel.

Cesco Announces New Welding Distributor Policy

Chicago Eye Shield Co., a manufacturer of safety protective equipment used by industry, has announced a new sales and distribution policy for welding equipment distributors. Prompted by the steady growth of its welding equipment line, the company says the policy assures new and existing welding equipment distributors that they can resell Cesco welding products at strictly competitive prices.

Gevaert Changes Atlanta Address

Gevaert Co. of America, Inc., formerly located at 598 Wells St., S. W., Atlanta 3, Ga., now has a new address 1297 Spring St., N. W., Atlanta 9, Ga.

This recent move not only gives Gevaert larger quarters, but permits ample room to carry larger inventories. It improves local product availability to enhance service on Gevaert sensitized photographic products for customers in this area, according to the company.

Zero Announces New Division

The formation of Zero Research Laboratories as an operating division of Zero Manufacturing Co., was announced recently by President John B. Gilbert.

Gilbert said that the new division already has several classified projects in research, development and furnishing prototypes for missile programs. Zero Research Laboratories was formed to provide R & D and production for all types of metal joining, welding and epoxy bonding. This will include the rare earth metals such as columbium, zirconium, hafnium and others.

According to Gilbert, Kenneth Bence will be general manager of the new division. Bence was formerly with Sciaky Research Laboratories and Electronic Welding Co. Headquarters of the new 10,000-sq ft facility are at 1000 Chestnut St., Burbank, Calif.

New Office for Chicago Bridge & Iron

Chicago Bridge & Iron Co., world wide steel plate fabricating and construction firm, broke ground June 12th for its new general office building some 20 miles west of downtown Chicago. Site of the building is an 11-acre tract of land bordered to the west by the East-West Tollway and to the north by 22nd St. in the Village of Oak Brook, Ill.

Workmen of The Austin Co., designer and prime contractor, started site preparation immediately after CB&I President E. E. Michaels and Village President Theodore Mohlman turned the first spadeful of dirt.

The fully air-conditioned building will provide 75,000 sq ft of floor space within its two stories. It will bring together some 350 CB&I executives and staff employees now located in corporate headquarters at 1305 W. 105th St. and the Loop office at 332 S. Michigan Ave.

Completion and occupancy of the new facility are set for early next spring.

Hyland Welding Installs Oxygen Converter

A new liquid oxygen pumping unit that provides a continuous supply of gaseous oxygen for customers has been installed at Hyland Welding Supplies, Evansville, Ill.

The unit enables Hyland to fill gaseous oxygen cylinders to high pressure by converting the easily stored low-pressure liquid. Liquid oxygen is delivered periodically to the dealer by the National Cylinder Gas Div. of Chemetron Corp., which installed the unit.

For details, circle No. 17 on Reader Information Card →

World's biggest power shovel welded with M&T Murex electrodes

Picture this 6,588,000 lb. giant on the 50-yard line of a football field. It could dig a 65 cu. yd. dipper-full in one end zone, lift it 140 feet high, swing its 170-ft. boom and pile the 100 ton load on a 12-story building in the opposite end zone. For many of the shovel's most important weldments, the builder, Marion Power Shovel Co., put its trust in M&T Murex electrodes – products of METAL & THERMIT CORPORATION, General Offices: Rahway, New Jersey.

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PERSONNEL

Brown Assigned to New All-State Post

Charles Brown AWS has been assigned to the new post of assistant to sales manager and director of technical service for All-State Welding Alloys Co., Inc., White Plains, N. Y. Mr. Brown was formerly divisional sales supervisor for the Midwest and South-Central sales region.

Mr. Brown has had 18 years of service in the welding field, following Technical Welding Institute, Army Ordnance training during World War II at the TNT plant of Atlas Powder Co. in Kentucky. Prior to his career in welding, Mr. Brown was principal of Taught School in Kentucky and holds a Bachelor of Science degree in education from Murray State College.

C. G. Herbruck Appointed Foundation Secretary

Dr. E. E. Dreese, chairman of the Board of Trustees of The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio, has announced the appointment of Charles G. Herbruck AWS as secretary of the Foundation. Herbruck has been assistant secretary since 1947 and has been acting secretary since the death of A. F. Davis, the organization's founding secretary. Herbruck is a graduate of Princeton University and has been active in the welding industry and the AMERICAN WELDING SOCIETY since 1942.

The James F. Lincoln Arc Welding Foundation was established in 1936 by the Lincoln Electric Co. for advancing knowledge of the art and science of arc welding through study and education. Its activities have centered in competitions for welded design of machinery and structures at both professional and student levels. The Foundation has also published books and other sources of data on arc welding and design. This information is made available to libraries, educational institutions and industry in general.

Wylie Named Director Of Southwest Research

Robert D. Wylie AWS has been named director of the Department of Materials Engineering of Southwest Research Institute. Wylie was formerly manager of quality control for the boiler division of the Babcock and Wilcox Co. in Akron, Ohio.

Mr. Wylie is a member of the American Society of Metals. In 1960, he was program coordinator for the National Metal Congress in Philadelphia. He is a member of several subcommittees of the Boiler and Pressure Vessel Code Committee of the American Society of Mechanical Engineers. He is a member of two standing Committees of the AMERICAN WELDING SOCIETY, and was a member of the Welding Research Council's Pressure Vessel Research Committee and the High Alloys Committee.

R. D. Wylie

C. A. Dauber

S. S. Bruce, Jr.

C. Brown

C. G. Herbruck

W. J. Hocker, Jr.

For details, circle No. 18 on Reader Information Card ——➤

World's toughest electrical machines welded with M&T Murex electrodes

Electrical engineers agree that the job of correcting power factor and regulating voltage requires the synchronous condenser to undergo some of the most severe mechanical and electrical stresses experienced in electrical machines. Rugged construction is a "must." Below is a 50,000-kva "electrical shock absorber" built by the Elliott Company. In welding its line of synchronous condensers, Elliott uses Murex electrodes—products of METAL & THERMIT CORPORATION, General Offices: Rahway, N. J.

M&T MUREX
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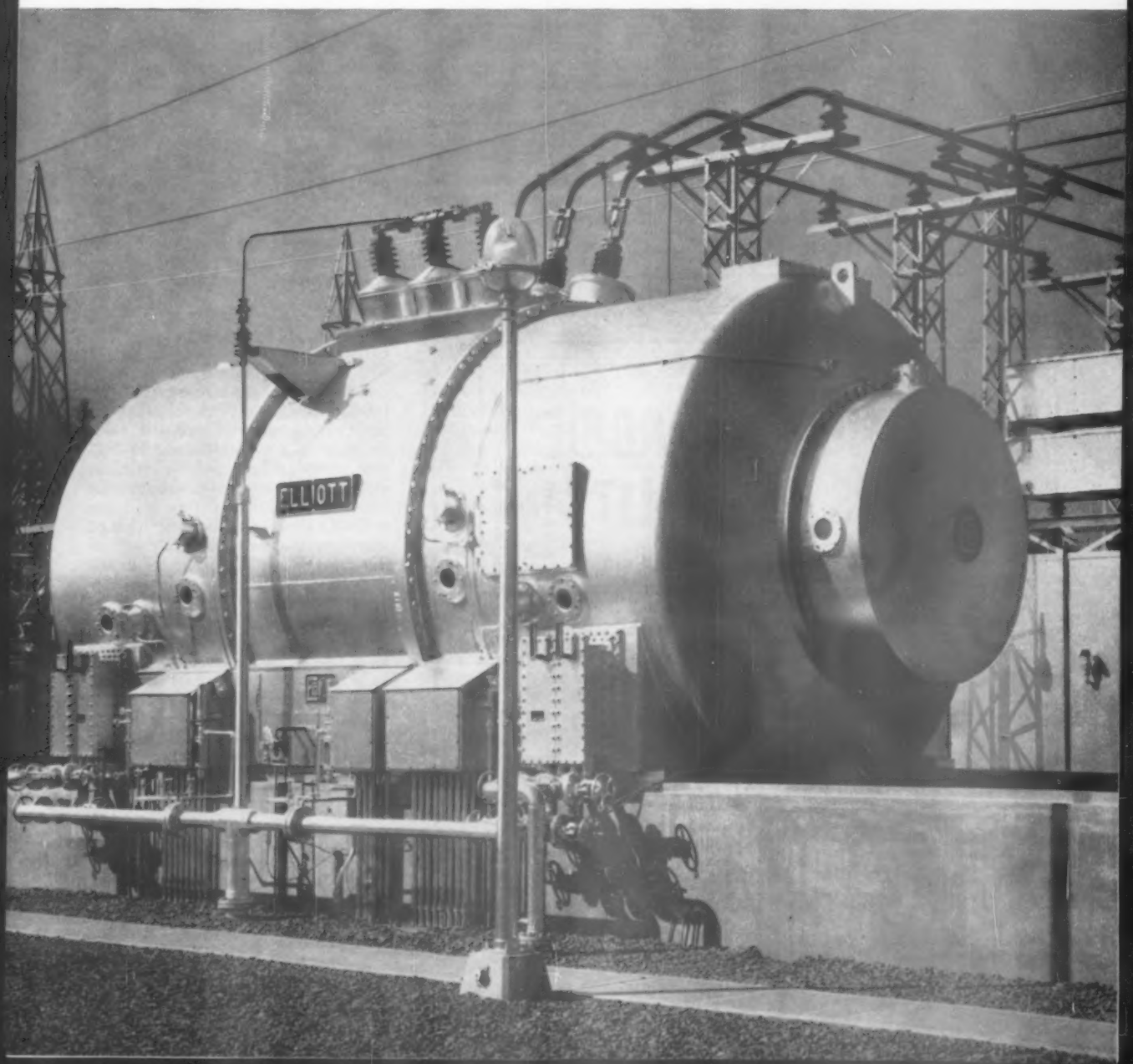

W. B. Moen

Moen Appointed Manager of Airco Cryogenic

W. B. Moen AWS has been appointed manager of the Air Reduction Sales Co. Cryogenic Engineering Dept. in Plainfield, N. J. In his new post, Mr. Moen will be responsible for the design and construction of major air separation and related cryogenic plants.

Associated with Airco since 1948, Mr. Moen started as an assistant engineer at the Research Laboratories, Murray Hill, N. J. Four years later he became section head, Metallurgical Process Div., and in 1957 was named assistant director of that division. In 1959, he was named engineering-manager for Airco's Special Products Dept. He was subsequently appointed assistant manager of the Cryogenic Engineering Dept., a post he held until his present promotion.

C. A. Dauber Named Power Head

Clarence A. Dauber AWS has been appointed to head the thermal power engineering activities of Chas. T. Main, Inc., the Boston consulting firm announced recently. Mr. Dauber is presently director of the Civil and Mechanical Engineering Division for the Cleveland Electric Illuminating Co., and occupied his new position on July 1, 1961.

Mr. Dauber joined the Cleveland Electric Illuminating Co. in 1928. He has been associated with the design and construction of over two million kilowatts of power plant capacity, and has provided consulting services on a wide variety of operating problems. Mr. Dauber has been active in coal pipe-line development since its inception.

Dauber is on the Board of Governors of the Cleveland Engineering Society, and is vice chairman of the Prime Movers Committee of the Edison Electric Institute. In addition, he is a member of the Ohio Chamber of Commerce, American Society of Mechanical Engineers and Ohio Electric Utility Institute, and served on the Industrial Wastes Committee of the Cleveland Chamber of Commerce.

Westinghouse Appointments

New executive appointments in the Westing-Arc Dept. of Westinghouse, Buffalo, N. Y., have been announced by Richard C. Lipps, department manager.

Fred J. Purdy AWS, a veteran Westing-Arc sales executive, has been appointed manager of sales. Purdy will be responsible for all sales personnel direction, channels of distribution, loadings realization, expense control and sales engineering support.

Philip W. Mahin, formerly market planning specialist, has been appointed administrative assistant to Mr. Purdy. In his new assignment, Mahin will be responsible for market analyses, billings performance measurements, field sales analyses and other administrative duties.

Bruce Named Railroad Sales Manager

S. S. Bruce, Jr. AWS has been appointed manager of Air Reduction Sales Co.'s national railroad sales department in Pittsburgh, Pa., it was announced by E. S. Twining, Jr., vice president-marketing. In his new post, Mr. Bruce will coordinate all sales and distribution of Airco products to the railroad industry. He replaces D. J. Williams who retired in June.

A graduate of Franklin & Marshall College, Lancaster, Pa., Mr. Bruce first joined Airco in 1946 as a sales representative in the railroad department. In 1954, he became district manager for the Chicago District. Two years later he was named district manager, Pittsburgh District, and subsequently, assistant manager of railroad marketing, a post he held until his recent promotion.

Davis Named Airco Supervisor

William T. Davis AWS has been appointed supervisor of manufacturing engineering for Air Reduction Sales Co.'s Cryogenic En-

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TOPS IN QUALITY!
All you want—when you want it in the RED DRUM.
All sizes, in quantities from 2 lb. pkgs. to 5 ton hoppers.
Calcium carbide is a product of:
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gineering Dept. in Plainfield, N. J., it was announced recently by W. B. Moen, manager of the department. Mr. Davis will supervise the fabrication of cryogenic equipment for all Airco's major air separation and related cryogenic plants.

A graduate of Newark College of Engineering with a degree in mechanical engineering, Mr. Davis first joined Airco in 1946 as a laboratory assistant. Shortly after his appointment as a process representative in 1953, he joined M. W. Kellogg Co. in Jersey City. He returned to Airco in 1956 as process engineer in the Special Products Dept. in New York City. Three years later he was transferred to the Eastern Regional Office as a regional engineer, a post he held until his most recent promotion.

Guy E. Sabin Named Sales Manager

Guy E. Sabin has been named general sales manager for Omark Industries, Inc. In his new position, Sabin, who has been sales manager for Omark's Fastening Div. since 1956, now takes charge of all United States sales and service activities for the company's Oregon Saw Chain, Fastening and Gramweld Stud Welding System divisions.

Collins Named Budd Manager

James C. Collins has been appointed marketing manager of the Instruments Div. of The Budd Co.

Prior to his new appointment, Mr. Collins had been manager, market research of The Budd Co. for the past two years. As marketing manager of the Instruments Div., he will have complete responsibility for all marketing and sales functions of the Division.

Mr. Collins joined Budd in 1956 as a cadet. In 1958 he became marketing supervisor for a year before being promoted to take charge of the Market Research Dept.

J. F. Thurston Named Liquid Carbonic President

John F. Thurston, vice president for special projects, General Dynamics Corp., was recently named a senior vice president of the corporation, and president of the corporation's Liquid Carbonic Div., with headquarters in Chicago.

As president of the Liquid Carbonic Div., Thurston succeeds Rex L. Nicholson, who resigned to devote himself to his other business interests.

Thurston came to General Dynamics in 1955 as manager of the Electro Dynamics Div. He has been a vice president and a member of the management board since 1957.

Baker Named Vice President

Election of David H. Baker by the board of directors of Vickers Inc., Div. of Sperry Rand Corp. as a vice president of Vickers and general manager of its International Div., was announced recently by president J. F. Forster.

Mr. Baker, who has been president of Capital Airlines, Inc., since 1957, succeeds R. E. Esch who has reached retirement age. Mr. Esch, a vice president of the Vickers organization and general manager of the company's International Div. for the past four years, will remain with the company as vice president and consultant.

Honorary Degree to Higgins

Theodore R. Higgins AWS, director of engineering and research, American Institute of Steel Construction, Inc., New York, N. Y., received an honorary degree at the 93rd Commencement Exercises of Lehigh University during June.

Other recipients of honorary degrees were: Charles H. H. Weikel, vice president in charge of research, Bethlehem Steel Co., Bethlehem, Pa.; Leonard P. Pool, president, Air Products, Inc., Allentown, Pa.; and Sir Hugh S. Taylor, president of the Woodrow Wilson National Fellowship Foundation at Princeton, N. J. and dean emeritus of the Graduate School at Princeton University.

NAAMM Directors

R. E. Morrison, Jr. AWS, Kentucky Metal Products Co., Louisville, Ky., and W. G. Zimmerman AWS, Architectural Metals, Inc., Denver, Colo., were recently picked with others to serve as directors of the National Association of Architectural Metal Manufacturers, Chicago, Ill., for 1961–62.

ASME Honors LeTourneau

Robert G. LeTourneau, pioneer builder of giant earth moving equipment that has been credited with "changing the face of the earth," received the Machine Design Award of The American Society of Mechanical Engineers in Detroit, Mich., at the recent Design Engineering Conference and Show.

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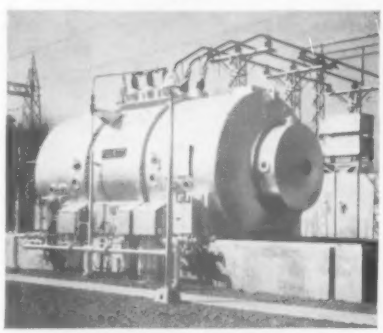

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Mr. LeTourneau was cited by the ASME for "outstanding achievement and distinguished service in the field of Machine Design; for innumerable ingenious engineering contributions associated with the design and production of a wide variety of heavy machinery in earth-moving and other heavy-duty materials handling." He was previously honored by ASME with promotion to the grade of fellow.

Lincoln Promotes Engineers

Lincoln Electric Co., Cleveland, Ohio, announces the transfer of David B. Reader AWS from Albany, N. Y., to its Dayton, Ohio, office.

Jack B. Paskins and James W. Rosenthal, after completing a one year training course at the factory, were appointed to Lincoln's staff of field engineers and assigned to the Albany and Pittsburgh offices respectively.

Taylor Joins Alloy Rods

O. M. Taylor has joined the sales staff of the Hard Surfacing Div. of Alloy Rods Co. F. L. Blodgett, AWS general manager of this division, announced that Taylor, a district manager, will operate from the company's sales office and warehouse in Birmingham and will cover the Southeastern region of the country as a specialist in hard surfacing.

Vickers Appoints Everett

The appointment of Robert T. Everett as manager of selenium process for Vickers Inc., Electric Products Div., St. Louis, has been announced by G. H. Clayton, general manager of the division.

Everett has previously been associated with Syntron Co. as supervising engineer, Silicon Rectifier Department.

Boberg Becomes Board Member

I. E. Boberg AWS, Chicago Bridge & Iron Co. engineering executive, was elected to the firm's board of directors during a recent meeting of shareholders in Chicago.

Mr. Boberg has been CB&I's chief engineer since 1945 and engineering vice president for the past four years. During World War II, he was in charge of engineering and construction of floating dry docks at a shipyard operated by the company at Morgan City, La.

Mr. Boberg is a registered structural engineer in Illinois and a fellow of the American Society of Civil Engineers. He also is a member of the American Society for Testing Materials, National Association of Corrosion Engineers, and the American Council of the International Institute of Welding.

He is chairman of the pressure vessel committee of the Welding Research Council, chairman of the AWS committee on rules for field welding of steel storage tanks and is a member of several committees.

Kocher Named Assistant Manager

W. J. Kocher, Jr. AWS has been appointed assistant manager in charge of engineering services for Air Reduction Sales Co.'s Minneapolis District, according to D. F. McCandlish, midwestern regional sales manager. In his new capacity, Mr. Kocher will direct technical services to customers in the Minneapolis District.

A graduate of the Massachusetts Institute of Technology with a degree in mechanical engineering, Mr. Kocher has been associated with Airco since 1954, when he started as a trainee in Central Research Laboratories of Air Reduction Co., Inc., in Murray Hill, N. J. He subsequently was appointed an engineer–engineering services in the Chicago District. In 1959, he was transferred to the Minneapolis District in a similar capacity, a position he held until his most recent appointment.

Bailey Selected

Lessells and Associates, Inc., of Boston, Mass., recently announced the election of Fred C. Bailey AWS as President. Professor John M. Lessells, founder of this firm and former president, will become chairman of the board and a consultant to the company.

Mr. Bailey graduated from MIT in 1948 and received his Master's Degree from the same institution in 1949. After graduation, he served successively as a research engineer with the Caterpillar Tractor Company, and technical secretary, assistant, and then acting technical director of the Committee on Ship Structural Design of the National Research Council. His association with Lessells commenced in 1955, where he has served as project engineer, senior project engineer, and executive vice president.

Affiliations include the American Society of Mechanical Engineers and the Society for Experimental Stress Analysis, which he serves as a member of the Executive Committee.

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Two Elected to Chemetron Board

Two new members of the Chemetron Corp. board of directors, William W. Whitnell, corporate vice president, secretary and controller, and Roy T. Omundson, corporate vice president and president of the Cardox Div., were elected by stockholders at the Chemetron annual meeting.

Whitnell joined the company in 1943 as controller, became secretary in 1946 and vice president in 1957. Omundson, vice president since 1959, has been president of the Cardox Div. since 1958 and was previously president of Cardox Corp.

Ingalls Realigns Executive Staff

The Ingalls Iron Works Co., Birmingham, Ala., recently announced the following executive staff changes: M. H. Osburn to vice president of finance as well as treasurer and controller; D. H. Bradley AWS, director of manufacturing; Ross S. Anderson, director of marketing; C. T. Capp AWS,

general manager of sales—custom products; H. G. Miller, general manager, sales—standard products; F. W. Atchison, Jr., staff manager, central marketing services; George W. Sorrell AWS, manager, marine and plate sales—Southern Region; R. P. Sandefur, manager, structural sales—Southern Region; W. J. Daley, manager, sales—Central Region; and K. A. Hiller, manager, sales—Northern Region.

Green Elected

The election of George L. Green as vice president in charge of marketing was recently announced by Pullman-Standard, Chicago, Ill.

Green succeeds T. P. Gorter, vice president, as head of Pullman-Standard's sales organization. Gorter, who completes 42 years of service, will continue with the company as a vice president, sales.

Wisconsin Honors Scheil

The University of Wisconsin, upon recommendation of the faculty of the College of Engineering and with approval of the Regents of the University, recently recognized the "eminent professional services" of Merrill A. Scheil AWS, in a citation for outstanding accomplishments as engineer, author, and administrator, who, through technical papers and lectures, effective leadership in many technical organizations and contributions to national defense, has significantly advanced the profession of metallurgical engineering.

Coast Metals Appoints F. K. Iverson

F. Kenneth Iverson has been appointed executive vice president of Coast Metals, Inc., Little Ferry, N. J., producers of hard facing materials, brazing alloys and alloy castings. Mr. Iverson was previously manager of sales of Cannon-Muskegon Corp.

Mills Appointed by RegO

The appointment of E. L. Mills II, as assistant sales manager, RegO Plant Equipment Div. under J. K. Calhoun AWS has been announced by R. H. Engstrom, vice president of RegO sales.

Mills, previous to this appointment, had five years experience with the Bastian-Blessing Co.'s Research Engineering Dept. and five years in the RegO LP-Gas Sales Dept.

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ASM Appoints Lyman

Taylor Lyman, editor of the new ASM Metals Handbook, 8th Edition, Volume 1, "Properties and Selection of Metals," has been appointed editor of reference publication for the American Society for Metals, according to Allan Ray Putnam, managing director of the society.

Amperex Announces Promotions

The promotion of Charles Roddy AWS from Product Manager, Transmitting and Power Tubes to the position of Technical Assistant to the President, was recently announced by Frank Randall, president of Amperex Electronic Corp., Hicksville, L. I., N. Y.

Mr. Randall also announced two other promotions: Ed King to Assistant Product Manager, Professional Tubes and Semiconductors, and Al Katz to Assistant Product Manager, Transmitting and Power Tubes.

OBITUARIES

Leigh Patterson

Leigh Patterson, of Miami, Fla., died on April 22, 1961, at the age of 58. He was a long time employee of Adelman Pipe and Steel Co. Inc., of Miami, a welding instructor at Technical High School, a member of the Elks, secretary of the Boilermakers Union and one of the founders and executive board members of the South Florida Section of the AMERICAN WELDING SOCIETY.

Surviving are his wife, son, mother and brother. His knowledge, service, guiding leadership and brotherhood will be long remembered.

Joseph F. Minnotte

Joseph F. Minnotte, died suddenly on June 12th in Pittsburgh, Pa. He was 72 years old.

At the time of his death, Mr. Minnottee was secretary treasurer of the Minnottee Brothers Co., which he founded with Charles V. and Albert A. Minnotte in 1921.

Mr. Minnotte joined the AMERICAN WELDING SOCIETY in 1919 and was elected secretary of the Pittsburgh Section in 1930. He served the Section in this capacity for thirty years. On April 29, 1960, at the Section's annual dinner he was presented with a testimonial, signed by the past chairmen, expressing the section's appreciation

J. F. Minnotte

for his thirty years of devoted service as secretary, the most appropriate phrase of which stated: "Your unselfish and untiring efforts have contributed greatly to the Section's growth and the professional development of its members." This phrase expressed the section's feeling for Mr. Minnotte.

Mr. Minnotte was also a member of the Engineering Society of Western Pennsylvania, Master Builders Association of Western Pennsylvania and the Tri-State Structural Fabricators Association, as well as the Getter C. Shidle Lodge F. & A.M.

Mr. Minnotte is survived by his wife, two brothers, three daughters, two sons and twelve grandchildren.

Abstracts of Current PATENTS

prepared by Vern L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington D.C

2,942,091—Method of and Apparatus for Welding Metal Tubes—Frank D. Hazen, P. O. Box 10597, Pittsburgh 35, Pa.

In this method of making seamless tubing by arc welding, a preformed tube blank with an open seam is subjected to an externally applied shaping and sizing pressure with the edges of the blank held in abutting relation to form the seam. The pressure is of a magnitude to prestress the metal to a degree in excess of any stresses imposed by the heat of the weld, and such shaping pressure is maintained during and after the application of the welding arc until the weld is cooled.

2,942,092—Internal Tube Cutter—Fred W. Cammann, 2700 Henninger Rd., Cleveland, Ohio.

This new internal tube cutter includes a driven drive shaft that has cutting means flexibly connected to the drive shaft and mounted off center with relation thereto so that the cutting means is moved into cutting engagement with the tube in which the cutting means is disposed when such means is rotated. Electric power circuit means is directed to the drive shaft and to the tube on which the cutter is working so that an arc will be created and the tube will be disintegrated at the point of contact when the cutting means engages the tube.

2,942,094—Method of and Means for Making Seam-weld Joints Between Metallic Members—Charles Samuel Broad, London, England, assignor to Gallay Ltd., London, England, a company of Great Britain.

This patent is on a method to make a seam-weld joint between metallic members in a structure and the method includes disposing the structure between a rotatable idler wheel electrode and a rod electrode. The structure is moved relative to the electrodes and pressure is applied to the rod electrode in a direction toward the idler wheel electrode and an electric welding current is passed through the electrode and the structure for weld action.

2,942,095—Temperature - operated Power Element—Thomas Herbert Robertson, Birmingham, Mich., assignor to American Radiator & Standard Sanitary Corp., New York, N. Y., a corporation of Delaware.

A cup and guide member of a temperature operated power element are secured together by the method of the present patent. Interfitting beads are formed in contacting flanges of the cup and guide members and such members are assembled with a diaphragm interposed therebetween. A welding current is applied to fuse the flanges to the guide and cup members to the diaphragm without melting the diaphragm through completely.

2,942,096—Apparatus for Electric Arc Stud Welding—Samuel O. Jones, Newport News, Va., assignor to Newport News Shipbuilding and Dry Dock Co., Newport News, Va., a corporation of Virginia.

This new stud welding gun includes a solenoid coil therein and a plunger controlled by the solenoid coil. The solenoid is energized when welding action is desired and the plunger has a controllable movement in the gun to aid in controlling stud positioning and welding action.

2,942,999—Laboratory Test for Determining Braze-ability of Copper-plated Steel Strip—Edward J. Roehl and Emory B. Michel, Warren, Ohio, assignors to Pittsburgh Steel Co., Pittsburgh, Pa., a corporation of Pennsylvania.

The present patent discloses a method for laboratory testing the brazeability of copper-plated steel strip and includes obtaining an immersion deposit of copper on a test strip. This deposit is compared with a pre-established rating schedule to determine the relative brazeability of the test strip.

2,943,179—Method and Apparatus for Welding Cylindrical Shells—Andrew P. Raiha, Chatham, Ont., Canada, assignor to Progressive Welder of Canada Ltd., Chatham, Ont., Canada, a corporation of Canada.

Raiha's patent relates to apparatus for making a cylindrical shell and it includes a support movable back and forth between the first and second stations. Means on the support form an annular mandrel with an axis parallel to the line of movement of the support. A device is included for applying force to a flat rectangular workpiece placed on the periphery of the mandrel to bend the central portion of the workpiece into contact with the periphery of the mandrel and other means at the first station apply a force to the intermediate portions of the workpiece between the central portion and the ends thereof to bend such portions into contact with the periphery of the mandrel. At the second station, a member is provided to apply a force to the ends of the workpiece to bring them into contact with each other and the periphery of the mandrel. A welding current is supplied to the ends of the workpiece, and means responsive to the increase in force caused by contact of the ends of the workpiece with each other for energizing such welding current means.

2,943,180—Steel Welding—David R. Kelker, Allison Park, Pa., assignor, by mesne assignments, to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

The present patent is on a method of welding a steel workpiece and it includes establishing a shielded arc between a wire consuming steel electrode and the workpiece. The wire electrode is coated with substantially pure aluminum. This aluminum coating is disposed uniformly on the electrode and constitutes between about 0.5–2.0% by weight of the electrode. The electrode is fed toward the arc at high speed as the electrode is melted by the arc and is transferred to the workpiece.

2,943,181—Brazing Process and Apparatus—Robert F. Gunow and Lester E. Oliphant, Detroit, Mich., assignors of one-half each to Vac-Hyd Processing Corp., Highland Park, Mich., a corporation of Michigan, and General Motors Corp., Detroit, Mich., a corporation of Delaware.

A method of vacuum brazing is disclosed in the present patent and it includes assembling the parts to be brazed with a suitable brazing material applied to the areas to be joined. This assembly is placed in a closed furnace, which is then evacuated, and heated to a temperature suitable for brazing. A gettering agent is vaporized into the atmosphere of the furnace during the heating thereof to a temperature immediately below the brazing temperature. The furnace is next cooled, and the pressure therein is increased, and thereafter the assembly is removed from the furnace.

2,943,183—Electrode Holder—Forde M. Simms, Irvington, and John V. Warinsky, Oradell, N. J., assignors to Falstrom Co., Passaic, N. J., corporation of New Jersey.

This patented electrode holder is for use in electric arc welding and includes an electrode-supporting means including a conduit formed into a helix and connected to one end of the electrode-supporting means to provide flexible mounting for the electrode-supporting means to permit angular displacement of the electrode-supporting means.

2,943,387—Process of Circumferentially Welding Steel Pipe—Lester K. Dawson, Coatesville, Pa., assignor to Lukens Steel Co., Coatesville, Pa., a corporation of Pennsylvania.

Dawson's process is for uniting the confronting ends of a pair of clad steel pipe sections where the outer layer consists of a carbon steel base metal and the inner layer consists of a cladding layer of corrosion resisting metal. In the method, circumferential lands are formed in the confronting ends of the pipe sections composed entirely of cladding metal and inclined circumferential portions are provided in the base metal extending from the lands to the exterior periphery of the pipe sections. A circumferential sealing weld bead is laid from the outside of the sections with a filler rod of metal of substantially the same composition as the cladding layer, and partially filling the trough formed by the inclined portions at the pipe sections until the corners formed by the junctures of the inclined portions and the lands have been entirely covered with welding material. The weld is then completed by filling the trough formed by the inclined portions and the sealing bead with welding material of substantially the same composition as the base metal.

2,943,388—Method of Making Corrosion Resistant Clad Steel Plate—Richard S. Rote, Coatesville, Pa., assignor to Lukens Steel Co., Coatesville, Pa., a corporation of Pennsylvania.

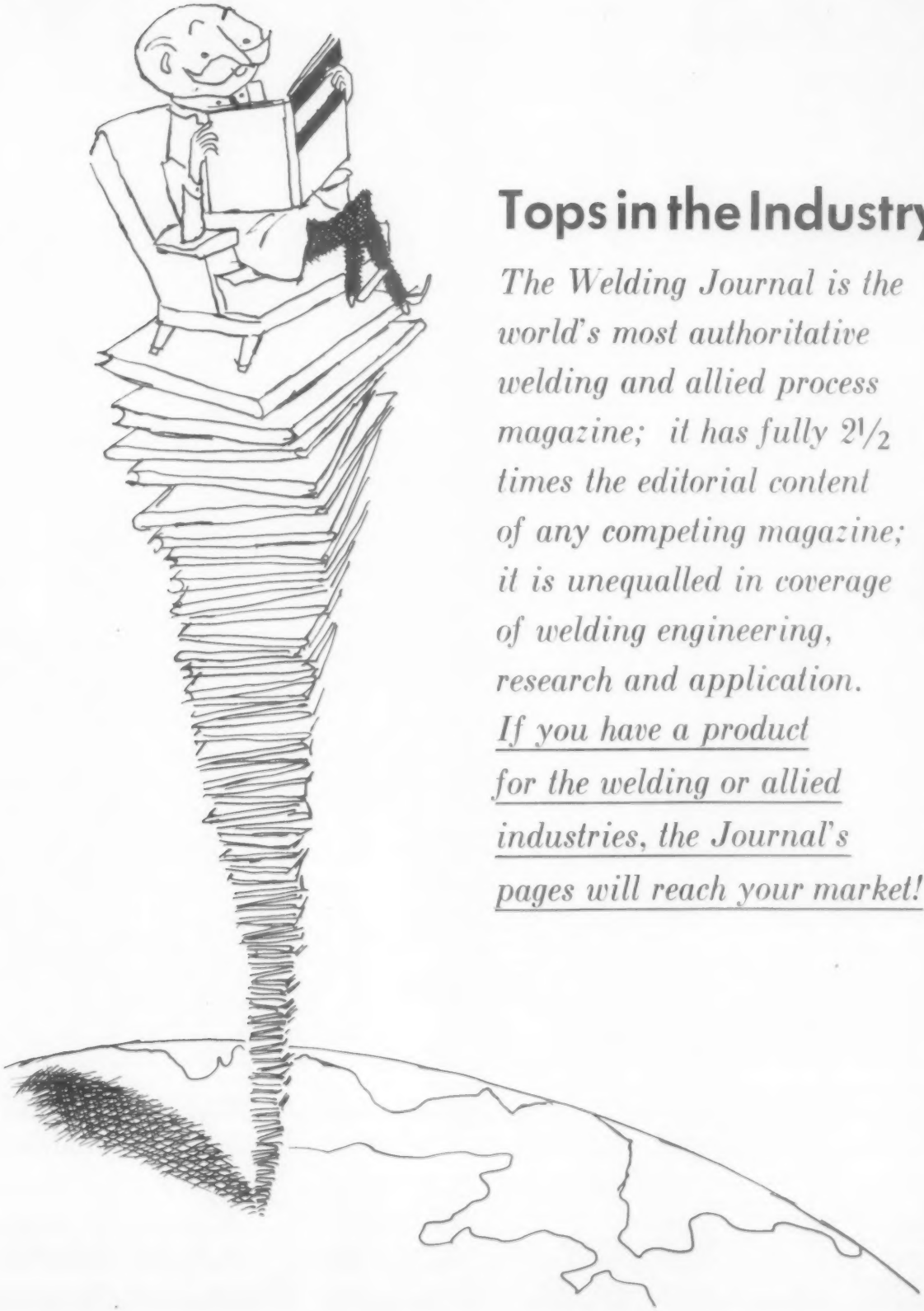
In Rote's method, a composite rectangular carbon steel plate is provided. Initially a plurality of pairs of grooves are formed in the bottom face of a corrosion resistant cladding plate. The cladding plate, with its specially formed grooved surfaces thereon, is provided with the grooves in contacting face-to-face relation with the carbon steel backing plate having a different coefficient of expansion than the cladding plate. A welding groove is provided in the edge of the assembly at the contacting faces of the plates and welding metal is deposited in such groove to seal the plates together. The assembly is then heated to welding temperature and rolled to weld the surfaces together and also to roll the surfaces and plates to the desired gage.

2,944,339—Method of Brazing Refrigerator Evaporators—Ray A. Sandberg, Waukegan, Ill., assignor to Houdaille Industries, Inc., a corporation of Michigan.

Sandberg's patent is on a method of making a refrigerator evaporator and includes the step of superimposing an inner shell of flat sheet metal and an outer shell of sheet metal having outwardly embossed portions and flat planar portions thereon and with a layer of brazing material being provided between the shells for forming an assembly thereof. Then specialized brazing and compression actions are exerted on the sheets to effect the desired attachment therebetween.

2,944,891—Brazing Alloys—Arthur T. Cape, Los Angeles, Calif., assignor to Coast Metals, Inc., Little Ferry, N. J., a corporation of Delaware.

The new brazing alloy contains from about 2.5% to about 20% gold, from about 0.5% to about 3% boron, from about 0.5% to about 3.5% silicon, from about 10% to about 30% manganese, and the remainder is substantially composed of nickel.



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Welding Operators

Lloyd's Register Requirements in Testing of Welders, F. B. Bowring. *Brit. Welding Jnl.*, vol. 8, no. 1 (Jan. 1961), pp. 1–3.

Weld Properties

Influence of Ferrite on Properties of Deposited and Parent Metal of Welds in Chrome-Nickel Austenitic Steels, A. E. Runov and K. V. Lyubavskii. *Welding Production* (translation of *Svarochnoe Proizvodstvo*), (Sept. 1959), pp. 42–52.

Weld Testing

Inspection and Testing of Aluminium Welds, J. G. Young. *Light Metals*, vol. 23, no. 268 (Sept. 1960), pp. 248–252.

For details, circle No. 23 on Reader Information Card→

Jetweld Low Hydrogen Electrodes were used to make the welds in this costly complex of refinery pipes. Not only were they made fast, which is important to low costs, but they were made right. Tight. Porosity free. Crack free. Lincoln makes three **Jetweld Low Hydrogen** electrodes. Read inside how they can improve weld quality, speed your work, cut your welding costs.

These are Lincoln JETWELD low hydrogen electrodes on the job

By using high yield point alloy steel rather than carbon grade in these structural columns, architect was able to reduce column size 75%. This reduced building cost, increased rentable floor space. **Jetweld LH-70** electrodes were chosen to make the butt welds because of their ability to produce dense, crack-free joints on alloy steels.

These gasoline storage tanks represent excellent examples of how **Jetweld Low Hydrogen** electrodes can be used to save money in vertical welding on fairly heavy plate. Plus these values . . . no underbead or micro-cracking . . . dense and porosity-free welds. With **Jetweld LH** electrodes you can use high currents, get high deposition rate and bead size.

With any combination of the three Lincoln **Jetweld Low Hydrogen** electrodes, **LH-70, LH-90** and **LH-110**, you can weld all kinds of joints in all positions on any hard-to-weld steels from high carbon to T-1 steel. Each **Jetweld** handles essentially the same way, welds well in all positions. Only difference among the three is physical properties which conform to the AWS specifications for 70-, 90-, and 110,000 psi class electrodes. With each of them, you can actually weld heavy plate faster and at less cost than with ordinary mild-steel electrodes. And, you'll get better welds that are crack-free, porosity-free and X-ray quality.

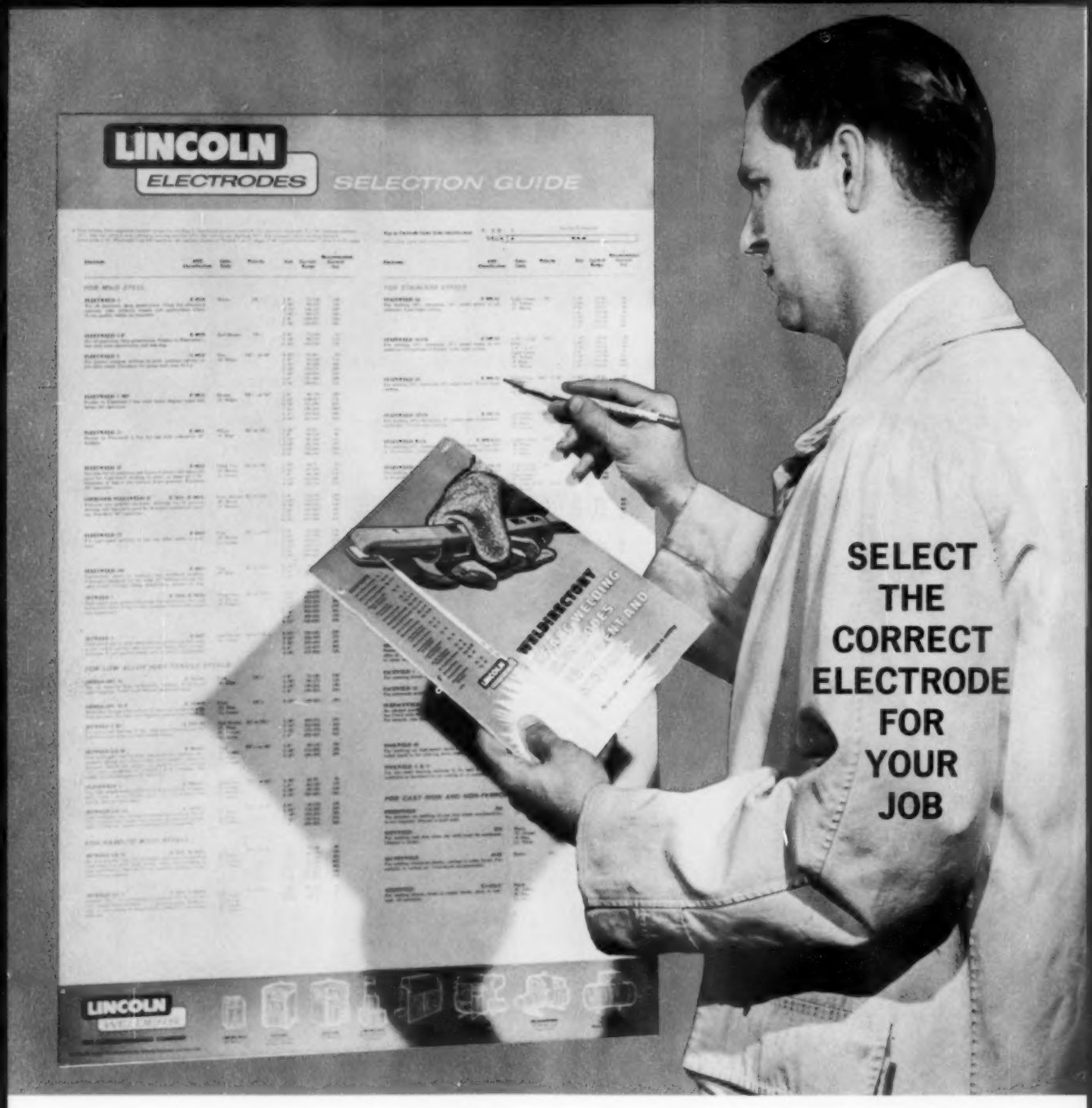
LINCOLN ELECTRODES

Although **Jetweld LH-70** electrodes do cost slightly more than regular 6010-11 electrodes, their use can actually reduce the finished cost even in vertical welding, particularly on ⅛-inch plate or thicker. Why? Because you can use higher currents which produce a correspondingly higher deposition rate and bead size. These, in turn, reduce the number of passes necessary to complete the weld. **Jetweld Low Hydrogen** electrodes deliver better mileage — length of weld per electrode — too. Not the least important, **Jetweld** electrodes significantly reduce and often eliminate the need for costly, time-consuming pre-heating. This factor alone could rule out all other electrode possibilities on many applications.

Equip your shop with Lincoln **Jetweld Low Hydrogen** electrodes and you'll find there's no such thing as hard-to-weld steels. They handle large, tough jobs quickly, well, and at low cost. Want to know more about them? Why not let your Lincoln field engineer . . . a specialist in welding . . . fill you in. There's no obligation, of course. Or, you might prefer to check the next page for bulletins which will help you solve many of your electrode selection problems.

Pressure vessel components fabricated from heavy plate such as this can be done most economically and with confidence with **Jetweld Low Hydrogen** electrodes. You can count on **Jetweld LH** electrodes where code requirements call for X-ray quality. And costly pre-heating can be reduced, even eliminated on many such jobs.

Here, **Jetweld LH-70** electrodes are used to join the bottom flange of a beam to building column. The higher useable currents with these electrodes can increase the deposition rate and welding speed. And **LH-70's** ability to give perfect welds on off-analysis steel, so often delivered for structural use, is a great reassurance for contractors.



Call your Lincoln Welding Specialist, or write for these free guides to Electrode Selection!

Your Lincoln field engineer has helped solve thousands of welding problems in all kinds of industries. His time and talents are yours. Why not use them to help you decide the proper electrode to handle your needs, particularly when you have an immediate problem that demands all the know-how you can draw from.

But for now, you may prefer simply to have a Lincoln Weldirectory or the newly-published Lincoln Electrode Selector Guide. The Weldirectory lists all Lincoln electrodes, discusses applications, techniques. The Electrode Selector Guide is a large 21½" x 33" wall chart which you can mount on your shop wall. It, too, lists all electrodes, applications plus an additional column which shows recommended machine current settings for each electrode and job type. Get either or both from your Lincoln specialist, or write today to:

LINCOLN ... USA

THE LINCOLN ELECTRIC COMPANY

Dept. WW-18123 • Cleveland 17, Ohio

The World's Largest Manufacturer of Arc Welding Equipment and Electrodes

New Literature

Metal Literature Review

The American Society for Metals, Metals Park (Novelty), Ohio, has published the *ASM Review of Metal Literature, 1960*, (Vol. 17) edited by Marjorie R. Hyslop.

The book contains 11,903 annotations of articles, technical papers, reports and documents appearing in engineering, scientific and industrial journals and books throughout the world during 1960. The volume is divided into 20 sections covering different areas of materials and process engineering and technology, and includes addresses of publications as well as comprehensive subject and author indexes.

Copies of this clothbound, 6- x 9-in., 1342-page volume may be ordered from ASM Headquarters at $25 each. Back issues are available at $20 per copy.

Template Preparation Reprints Available

Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y., has just issued reprints of an article by L. M. Layden entitled, "Principles of Template Preparation for the Oxygen Gas Cutting Process." Mr. Layden heads the mechanical section of the Equipment, Engineering and Development Dept. at Airco's Union, N. J., plant. The article was presented as a paper at the AMERICAN WELDING SOCIETY National Fall Meeting in Pittsburgh, Pa., and appeared in the January 1961 issue of the WELDING JOURNAL.

The liberally illustrated article presents the scanning principles of the line and edge tracers and relates the techniques of template preparation for each system. Techniques for compensating cornering errors produced by the tracers are discussed and kerf correction is treated.

Various other factors influencing the final accuracy of the cut parts are reviewed, and the paper concludes with a discussion of the relative advantages of the two types of tracers.

For your free copy, circle No. 51 on Reader Information Card.

Emission Spectrochemical Analysis

The American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., announces the publication of the 3rd edition of *Methods for Emission Spectrochemical Analysis, E-2*. The volume contains 119 standards, tentative standards, proposed and suggested methods. This compares to 90 methods published in the 1957 edition.

This compilation contains all the spectrochemical practices and methods published by ASTM. Also included are excerpts from ASTM methods or practices that are of direct interest to people making use of emission spectroscopy. Those recommended practices and tentative and standard methods pertaining to the spectrochemical analysis of metals are also included in the 1960 Book of ASTM Methods for Chemical Analysis of Metals.

Copies of this book may be obtained from ASTM Headquarters, 1916 Race St., Philadelphia 3, Pa., at $11 each.

ASTM Copper Standards

The American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., announces the availability of the 18th edition of the *Compilation of ASTM Standards on Copper and Copper Alloy—B-5*.

This compilation contains 134 standards of which 37 are new, revised or have had their status changed since the previous edition in 1959. In addition to standards for cast and wrought copper and copper alloys, the book contains material on nonferrous materials for electrical conductors, certain selected specifications on nonferrous metals and alloys for primary forms of copper, zinc, lead and nickel used in copper-alloy products.

Copies of this book may be obtained from ASTM Headquarters, 1916 Race St., Philadelphia 3, Pa., at $9.25 each.

Report on Available Standard Samples

Another aid to scientists studying materials is announced by the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., with the publication of a *Report on Available Standard Samples and Related Materials for Spectrochemical Analysis*.

The information is published in this volume to provide ready reference to the availability and sources of standard samples, reference samples and high-purity materials. The listing of high-purity materials provides useful information to the analyst, particularly in the preparation of standards in the laboratory when other suitable standard samples are not available.

Copies of this book may be obtained from ASTM Headquarters, 1916 Race St., Philadelphia 3, Pa., at $3.75 each.

Cemented Carbide Products Standard

The Cemented Carbide Producers Assn. has announced a new Simplified Practice Recommendation listing standard stock items of the cemented carbide industry, issued by the Commodity Standards Division, Office of Technical Services, U. S. Department of Commerce.

This publication is entitled "Standard Shapes, Sizes, Grades, and Designations of Cemented Carbide Products." The official government designation is R263-60.

The document covers forty-four items which are most popular in industry such as throw-away carbide inserts, saw tips, chisel blanks, die nibs, masonry drills and twist drill blanks. Each of the listings for the standard stock items are broken down according to the grade of carbide. A uniform system of identification of products is also described. Also included is a section dealing with nomenclature and definitions which should be of interest to anyone concerned with cemented carbides.

For your free copy, circle No. 52 on Reader Information Card.

Plant Maintenance Engineering Book

Publication of the 12th volume of "Techniques of Plant Maintenance & Engineering" in mid-June has been announced by Clapp & Poliak, Inc. The annual volume is a verbatim report of the Plant Maintenance and Engineering Confer-

ence, held in Chicago in January of this year, in conjunction with the Plant Maintenance and Engineering Show.

Bound in cloth-on-board, with 349 pages, 8½ x 11-in., it is considered the most extensive treatment of the subject ever published in this series. It contains the texts of 37 papers, illustrated by 114 charts, diagrams and tables, and supplemented by the discussions of 607 questions presented by the audience. In addition, the verbatim discussions of 155 subjects in 11 industrywide "problem sessions" are included.

The book, priced at $10 postpaid, may be obtained from Clapp & Poliak, Inc., 341 Madison Ave., New York 17, N. Y.

Welding Helmets

Welding Helmets with a new "3-C Headgear" by The Fibre-Metal Products Co., 5th & Tilghman Sts., Chester, Pa., are described in a 4-page Bulletin No. 73. The featured headgear is all smoothly-conformable plastic with headsize and crown adjustments, clean and fully sterilizable. Optional equipment is also shown to offer a wide variety of head and face protection.

For your free copy, circle No. 53 on Reader Information Card.

Optical Pyrometer Readings Table

Corrected Optical Pyrometer Readings, by D. E. Poland, J. W. Green and J. L. Margrave, National Bureau of Standards Monograph No. 30, is available from the U. S. Government Printing Office, Washington 25, D. C., at $.55 per copy.

The monograph contains 74 pages of a table which enables optical pyrometer users to convert immediately the observed temperature to the true temperature, taking into consideration the effective emissivity of the observed material. Conversely, the table can be used to determine the effective emissivity if the true temperature is known, by comparing this temperature with the pyrometer reading.

High-temperature Strain Gage Monograph

Development of High-temperature Strain Gages (monograph No. 26), published by the National Bureau of Standards, issued Mar. 17, 1961, containing 20 pages, is available from the U. S. Government Printing Office, Washington 25, D. C., at $.20 per copy.

Potential ceramic and metal components were evaluated and a gage was devised that was based on these evaluations. This gage (NBS 58) was flexible and easy to install; however, it lacked resistance stability at higher temperatures. In an attempt to minimize this deficiency, ceramic cements were developed that showed greater electrical resistivity than had been previously observed in the range 800-1800° F; also, a technique was devised for increasing the resistance to ground by applying a fired-on ceramic coating to the grid of a specially developed unbacked gage.

Multi-Arc Control Units for Tack Welding

Tack welding with d-c power from a multiarc system is reported to be facilitated by control units designed especially for the purpose, and is described in a new data sheet from J. B. Nottingham & Co., Inc., 441 Lexington Ave., New York 17, N. Y.

The "Weldline" welding resistor stations are available in portable single operator models, rated 90 or 130 amp, or six-drawer units for 110, 135, 150 or 180 amp per welder. For higher welding currents, units are readily connected in parallel.

Although primarily for d-c metallic arc welding with coated electrodes in all positions, the control resistors can also be used for gas shielded tungsten, consumable electrode and other electric arc welding processes. Units are convection cooled, without fans or other moving parts.

For your free copy, circle No. 54 on Reader Information Card.

Thermophysics Handbook

A five-volume handbook of Thermophysical Properties of Solid Materials has been completed by the Armour Research Foundation of Illinois Institute of Technology, 35 W. 33rd St., Chicago 16, Ill., and is being issued as WADD Technical Report 58-476. The work was done under sponsorship of the Materials Central, Wright Air Development Division, U. S. Air Force, and is to be published in hardback form by the Macmillan Co., New York.

Materials covered in the handbook's 4000 pages include elements, alloys, ceramics, cermets, intermetallics, polymerics and composite materials. Except for materials in the last two categories, only those melting above 1000° F are included.

For details, circle No. 55 on Reader Information Card.

Bridge Economy Booklet

"15 Ways to Reduce the Cost of Short Span Steel Bridges" has just been published by the American Institute of Steel Construction, 101 Park Ave., New York 17, N. Y., as an aid to bridge designers to achieve more bridge with less dollars.

The 8-page booklet was prepared to acquaint bridge engineers with the most recent developments and significant ideas in steel bridge construction. The booklet stresses simplified details of fixed and expansion bearings, diaphragms and drainage structures, and suggests design simplifications which present opportunities for sizeable cost reductions.

For your free copy, circle No. 56 on Reader Information Card.

Bibliography on Economics of Nuclear Power

A bibliography on the *Economics of Nuclear Power* prepared by the Atomic Energy Commission has been released to science and industry through the Office of Technical Services, Business and Defense Services Administration, U. S. Dept. of Commerce, Washington 25, D. C.

Containing 518 selected references to research reports, articles, technical and scientific papers, the bibliography covers literature on the development of economical nuclear power for industry. Material is included on construction of power stations and reactors, materials used, processes employed, and other factors important in making economic evaluations.

To order this 82-page book (TID-3089), at a cost of $2, write to OTS, U. S. Dept. of Commerce.

Welding of Pressure Pipe

The Lincoln Electric Co., Cleveland 17, Ohio, has announced the availability of Bulletin 2112.2 "Welding Pressure Pipe Lines and Piping Systems" which contains practical information on techniques and costs related to cross country transmission and pressure piping systems. Hand welding techniques are described for depositing sound welds vertical up or down with pipe axis in vertical or horizontal positions. Procedural information for full automatic submerged-arc welding is also presented. In addition,

the bulletin reviews API pipe specifications, analysis, and physical properties and contains charts on pounds of electrode consumed per joint for various diameter pipe using either hand or full automatic submerged-arc welding.

For your free copy, circle No. 57 on Reader Information Card.

Rectifiers for Welding

"Questions and Answers on Rectifiers for Welding" (Form SR-3-61) is the title of an eight-page booklet which is now available from the Miller Electric Manufacturing Co., Appleton, Wis.

Answers are provided to thirteen "commonly asked" questions that often come up regarding rectifier type welding machines. A practical explanation is provided why selenium stands up better than silicon in rectifiers.

For your free copy, circle No. 58 on Reader Information Card.

Welding Positioners

The Aronson Machine Co., Arcade, N. Y., has made available a 28 page article by Charles N. Aronson which discusses welding positioners, the many features that are necessary and how these features work for the users benefit. Information on application of welding positioners for increased profits and comprehensive specifications on 1000 to 24,000 lb capacity models is also given. The article is Section 8 of "Positioneering."

For your free copy, circle No. 59 on Reader Information Card.

New Industrial X-ray Handbook

Gevaert Co. of America, Inc., has released a 25-page illustrated handbook on industrial X-ray films marketed by Gevaert.

The booklet contains comparison tables of the five Gevaert Structurix industrial X-ray films, technical data and sensitometric curves on each of the five films. The handbook also contains charts showing suggested exposures for magnesium, aluminium, steel and bronze, along with exposure charts for cobalt 60 and iridium 192 with steel.

In addition, there is also a section on processing X-ray films, charts showing film sizes converted to square footages, and a table of common logarithms.

For your free copy, circle No. 60 on Reader Information Card.

Hard-surfacing Data

A new 8½ x 11 Technical Data Sheet (No. T-2) discussing recommendations for finishing Colmonoy hard-surfacing alloy deposits is now available from Wall Colmonoy Corp., 19345 John R St., Detroit 3, Mich.

Specific grinding wheel recommendations for nickel base, cobalt base and iron base alloys are presented in tabular form listing eleven different wheel manufacturers. In each case, where applicable, the best wheel of a given make is listed with regard to surface (both horizontal and vertical), cylindrical, internal, centerless and tool room grinder operations.

For your free copy, circle No. 61 on Reader Information Card.

Method to Overlay Dissimilar Metals

Reprints of an article (Form ADR 132) by Ralph D. Engel entitled, "New Techniques for Cladding with the Gas-Shielded Process," have just been made available by Air Reduction Sales Co., 150 E. 42 St., New York 17, N. Y. Delivered as a paper before the 1960 American Welding Society convention in Los Angeles, the article appeared in the December 1960 issue of the WELDING JOURNAL.

Liberally illustrated, the article provides complete background in-

Now you can check
WELD TIME with
new PORTA-COUNT
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only $282

Counts actual weld time during firing. PORTA-COUNT is light and small enough to carry easily—keep right on the job. Completely portable and self-contained with long life (up to 2 years) batteries. Counts single phases.

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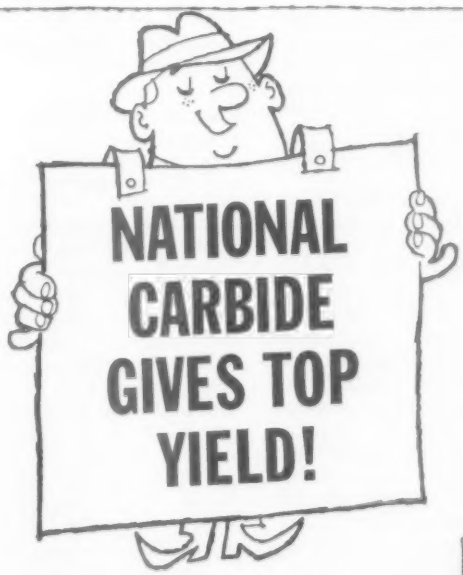

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formation on the development of a unique method of overlaying dissimilar materials. This new adaptation makes possible for the first time the cladding of materials with more precise control of weld metal dilution and quality. This process is presently being used in the cladding of nuclear reactor shells.

For your free copy, circle No. 62 on Reader Information Card.

Metal Powders Data Sheet

A new 8½ x 11 technical data sheet (No. T-3) discussing selection of metal powders for sprayed overlays is now available from Wall Colmonoy Corp., 19345 John R St., Detroit 3, Mich.

The literature discusses both standard metallizing procedure and the Sprayweld Process. It lists characteristics of each method and the materials that can be applied. A table of comparative values for 5 different Colmonoy hard-surfacing powders is also included.

For your free copy, circle No. 63 on Reader Information Card.

Rented Automatic Lift Trucks

Lease and rental finance plans offered by the Automatic Transportation Co., 149 W. 87 St., Chicago 20, Ill., to buyers and users of the company's industrial lift trucks are explained fully in a new 12-page booklet entitled "Which Is Best for You?"

For your free copy, circle No 64 on Reader Information Card.

Small Business Handbook

Profitable Management for Main Street, a 48-page handbook of small business, is available from Dun & Bradstreet, Inc., 99 Church St., New York 8, N. Y. The booklet contains information on management practices for the small-business operator.

For your free copy, circle No. 65 on Reader Information Card.

Welding of Mild, Low Alloy Steels

An informative, attractive 20 page catalog on the Welding of Mild and Alloy Steels is now available from the McKay Co., 1005 Liberty Ave., Pittsburgh 22, Pa.

The book contains complete information on specifications, operating characteristics, mechanical properties, applications and other pertinent data on the company's mild steel and low hydrogen electrodes available for fabrication of mild and alloy steels.

Several pages are devoted to handy reference charts listing the recommended electrodes in the welding of trade name steels, and ASTM carbon and low alloy steels. Also included is a page on Welding Terminology, plus a section on the cause and prevention of common welding troubles such as poor fusion undercutting, porosity, poor weld surface, weld cracks, etc.

For your free copy, circle No. 66 on Reader Information Card.

Capacitor Information

Power Factor Correction Capacitors for Arc Welding Applications (GEZ-3306) four pages, illustrated, describes capacitors rated 10–70 mfd, 236–460 v manufactured by General Electric Co., Schenectady 5, N. Y. Brochure discusses temperature, mounting, operating voltage, capacitance vs. temperature, frequency and other application information; new construction features; and ratings and dimensions.

Designed for arc-welding applications, the capacitors provide magnetizing current close to the use point to permit savings on line losses and boost output voltage.

For your free copy, circle No. 67 on Reader Information Card.

Track Rebuilding Equipment Catalog

A new, 16-page catalog picturing and describing Victor equipment for rebuilding track-type track assemblies, has just been released by Victor Equipment Co., 844 Folsom St., San Francisco 7, Calif., manufacturer of welding apparatus, gas regulators and hardfacing rods. Machines shown include: automatic roller and idler rebuilders, automatic grouser shoe and sprocket reconditioner, automatic track link welder, grouser bar welder, flux grinder, roller boring tool, roller flange flame hardener, roller and idler press, roller and idler grinder, pantograph, and accessories.

For your free copy, circle No. 68 on Reader Information Card.

Connector For Welding Cable

Bulletin No. 124-BP covers a new ball-point cable connector of the quick-detachable type made by Tweco Products, Inc., P. O. Box 666, Wichita 1, Kan. The connector has the accepted ball-point method of attaching cable. It is reportedly the quickest, simplest and easiest to apply in shop or field.

Three connector sizes No. 1-MBP, No. 2-MBP and No. 4-MBP, are available for 4 through 4/0 welding cable. A quarter turn locks the connector. A split male plug permits springing for adjustment of connector tension.

Neoprene covers insulate connectors for cable sizes 1/0 through 4/0; fiber covers for cable sizes 4 through 1/0. The ball-point type cable connector is interchangeable in the circuit with like sizes of other Tweco quick-detachable connectors.

For your free copy, circle No. 69 on Reader Information Card.

Metal Cleaning, Processing Brochure

Turco Products, Inc., 24600 S. Main St., Wilmington, Calif., announces the release of a new, comprehensive 12-page metal-finishing brochure titled "Specialized Chemical Processing Compounds for the Metalworking Industry."

For your free copy, circle No. 70 on Reader Information Card.

Seven-In. Grinder Bulletin

A bulletin describing the new Delta 7-in. grinder featuring patented "Twin Lite" safety shields is now available from Delta Power Tool Div., Rockwell Manufacturing Co., 488 N. Lexington Ave., Pittsburgh 8, Pa. According to the bulletin, the grinder's newly-designed safety shields contain double-strength, shatter-proof glass to protect the operator's eyes even if he fails to wear protective goggles.

For your free copy, circle No. 71 on Reader Information Card.

Arc Welding at Work

Number 166 "Hobart Arc Welding News," a 24-page booklet of interesting photographs and articles on welding from all over the country, is now available from Hobart Brothers Co., Troy, Ohio. Copies are mailed to anyone interested in manual and the automatic arc-welding processes.

For your free copy, circle No. 72 on Reader Information Card.

Dip-brazing Brochure

Dip brazing, the aluminum fabrication technique designed to produce economical, quality-assured components for a wide line of hard-

ware items used in aero-space, electronics and commercial fields, is the subject of an 8-page illustrated technical brochure prepared by Precision Dipbraze, Inc., 12031 Vose St., N. Hollywood, Calif.

For your free copy, circle No. 73 on Reader Information Card.

Build-up and Hardfacing

Well-illustrated, 16-page catalog by American Manganese Steel Div. (Dept. A) American Brake Shoe Co., 389 E. 14th St., Chicago Heights, Ill., carries product features, ordering information and prices on complete line of hardfacing and manganese steel build-up material. Includes rods, electrodes tooth repointers, bar, plate and special shapes. Typical applications are shown.

For your free copy, circle No. 74 on Reader Information Card.

Standard Relays Catalog

A new, 8-page catalog showing more than 40 standard P&B relays is available from Potter & Brumfield Division of American Machine & Foundry Co., Princeton, Ind. Descriptions, dimensions, technical specifications and prices are given for more than 450 variations of the basic relays.

For your free copy, circle No. 75 on Reader Information Card.

Pipe Dimension Chart

Midwest Piping Div., Crane Co., Box 433, St. Louis 66, Mo., has published a 17 x 11-in. pipe dimension chart showing outside diameter and wall thickness for all sizes of pipe from $^1/_2$ through 42 in. The chart includes information from ASA Standard B36.10, showing IPS and schedule numbers and their relationship, and includes latest wall thicknesses added in the 1959 revision.

For your free copy, circle No. 76 on Reader Information Card.

Welded Steel Tubing

With welded carbon steel tubing being used increasingly for heat transfer applications, Revere Copper and Brass, Inc., 230 Park Ave., New York 17, N. Y., has issued a new four-page brochure entitled, "Revere Electric Resistance Welded Steel Pressure Tubing." The brochure describes the production and testing of welded tubing.

Use of the "electric resistance" method in the production of Revere welded steel tubing provides an end product made strictly to specification, the brochure declares. The steps followed in producing a "weld that is as strong or stronger than the parent metal" are described.

For your free copy, circle No. 77 on Reader Information Card.

Weld Grinding Abrasive Wheels

A new catalog bulletin has been issued by Simonds Abrasive Co., Tacony & Fraley Sts., Philadelphia 37, Pa., about their Double XX and Fibrex reinforced, resinoid bonded abrasive wheels for grinding welds and stainless steel.

A new "U" grade of hardness has been established for Double XX wheels which increase wheel life with same cutting rate. General recommendations and operating data are presented in the bulletin.

For your free copy, circle No. 78 on Reader Information Card.

Machine Welding of Liquid Rocket Engines

Reprints of an article (Form ADR 133) by Ralph T. Hoetger and Walter B. Moen entitled, "Machine Welding of a Prepackaged Liquid Rocket Engine," have just been issued by Air Reduction Sales Co., 150 E. 42 St., New York 17, N. Y. The article was presented as a paper at the 1960 American Welding Society Show in Los Angeles and appeared in the October 1960 issue of the WELDING JOURNAL.

The dual-authored paper discusses high production, closely controlled machine welding of rocket engines with storable-propellent systems at Thiokol Chemical Corp., Reaction Motors Div., in Bristol, Pa. Liberally illustrated, the article presents a step-by-step account of engine construction.

Mr. Hoetger is plant manager of the Reaction Motors Div. facility in Bristol, while Mr. Moen is manager of the Cryogenic Department of Air Reduction Sales Co.

For your free copy, circle No. 79 on Reader Information Card.

Flex Drum Abrasive Wheels Technical Data Sheet

Merit Products, Inc., 3691 Lenawee Ave., Los Angeles 16, Calif., has announced the availability of its new Technical Data Sheet No. FD-30 to the metalworking and woodworking industry. The new pamphlet, amply illustrated, discusses features and applications of the Merit Type B Flex Drum, a super-resilient abrasive cloth wheel that simplifies sanding and polishing complex contoured surfaces.

The brochure lists grit grades available and describes the various configurations of the Type B Flex Drum. In addition, it covers rotation speeds and abrasive loading procedures.

For your free copy, circle No. 80 on Reader Information Card.

Power Distribution System for Preheat, Stress Relief

A safety-engineered distribution system to supply power to electrical resistance strip heaters for preheat and stress relief in welding is described in a data sheet issued by J. B. Nottingham & Co., Inc., 441 Lexington Ave., New York 17, N. Y.

Quickly installed "Duraline" plug-in equipment replaces the tangled wires and hazardous connections of improvised distribution hookups. Neoprene - insulated blocks, plugs and cables, waterproof connections, equipment-grounded circuits, and fused plugs protect personnel and equipment against electrical and physical hazards.

Equipment is available for 220- or 440-v systems. Heavy-duty, interchangeable units can be combined in a variety of circuits for use on job after job, reducing material costs as well as saving installation time.

For your free copy, circle No. 81 on Reader Information Card.

LIQUIDATION VALUES

EXPLOSION-PROOF ELECTRICAL EQUIPMENT

100-Disconnect Switches, 30 amp—600 amp, 3-pole, oil immersed, single throw, fused, 250 volts—600 volts.

150-Across-The-Line AC oil immersed, motor controlled Combination starters, 7$^1/_2$ hp.—25 hp., 440 volts.

26-Kinney High Vacuum Pumps, Model KDH-130, 131 cfm.

SMC INDUSTRIES, INC.
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For details, circle No. 26 on Reader Information Card

New Products

New Cast-iron Electrodes

Two new electrodes for the welding of cast iron have been introduced by Zenith Welding Products Co., Inc., 735 Lexington Ave., P.O. Box 211, Kenilworth, N. J.

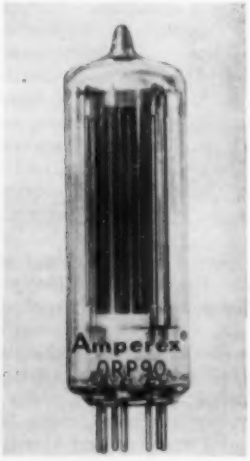
Zenith No. 1 "Ni-Core" electrode, a pure nickel electrode, features improved machineability and easy operability in the welding of ordinary cast irons. Zenith No. 2 "Ni-Fer-Core" electrode is intended for the welding of heavy sections, alloy irons and for the welding of cast iron to other metals.

Suitable for use in all positions with either ac or dc, both electrodes will be produced in diameters from $^{5}/_{32}$ to $^{3}/_{16}$ in., and, because of their reported versatility and ease of manipulation, are expected to simplify greatly the difficulties encountered in the welding of cast irons.

For details, circle No. 101 on Reader Information Card.

Cadmium Sulfide Cell with Top and Side Sensitivity

The Amperex Electronic Corp., Semiconductor and Special Purpose Tube Div., 230 Duffy Ave., Hicksville, L. I., N. Y., has announced the ORP 50, a light-sensitive cadium sulfide cell that is both top and side sensitive. This double sensitivity was accomplished by positioning the cadmium sulfide area at a 45 deg angle. The ORP 50 was so designed to further standardization.



Being hermetically sealed and of rugged all-glass construction, the ORP 50 can be used for both industrial and entertainment applications, such as: flame control, industrial on-off switching, relays, automatic counting and level and density control in industry.

Because flame control apparatus must be as small as possible, the ORP 50 has been provided with pigtail leads to save space and for versatility in mounting.

The ORP 50 measure only 0.63 in. in diam and 1.42 in. in length. Maximum dissipation is 250 mw. Average cell current is 10 ma.

For details, circle No. 102 on Reader Information Card.

Brazing Rod with Extruded Flux Coating

A brazing rod with a new extruded flux coating has been added to the line of oxyacetylene filler rods produced by Ampco Metal, Inc. Box 2004, Milwaukee 1, Wis.

The new coating is applied to the same Ampco-Braz core wire which has gained wide popularity in the brazing field. Identified as Ampco-Braz No. 2 FC, the new product is a low-fuming, free-flowing, manganese bronze brazing rod with reported excellent welding characteristics. The extruded coating provides exceptional cleaning and tinning action. Ampco-Braz No. 2 FC is ideal for high production applications where a prefluxed brazing rod is required.

For details, circle No. 103 on Reader Information Card.

Flash Welding Machine

A high-capacity, flash-welding machine recently designed and built by Thomson Electric Welder Co., 161 Pleasant St., Lynn, Mass., incorporates heavy duty electrical and mechanical arrangements that permit flash welding of aluminum to copper bar stock of the following sizes: (1) $^{3}/_{8}$ x 6 in., (2) $^{3}/_{8}$ x $1^{1}/_{2}$ in. and (3) $^{1}/_{2}$ x 3 in. The work is preheated, flashed and upset automatically using Thomson's synchromatic control and the resulting welds, produced in a matter of seconds, can withstand 180-deg bend tests.

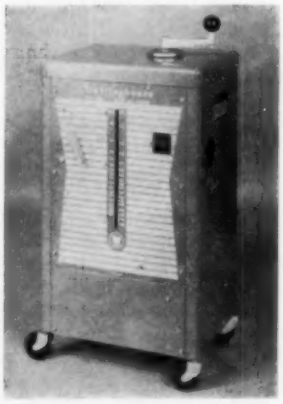
Rated as a 400 kva machine at a 50% duty cycle, the F-5 model machine is contained in a heavy fabricated steel frame measuring 82 in. high by 130 in. wide and 70 in. deep. Platens, electrodes and dies are at table height convenient to an operator.

For details, circle No. 104 on Reader Information Card.

300-amp A-C, D-C Arc-welding Unit

A new universal a-c, d-c arc welder with adaptable auxiliary equipment enabling use on any type of welding job has been introduced by the Westing-Arc Div. of Westinghouse Electric Corp., Buffalo, N. Y.

This 300-amp silicon rectifier model TR operates from single



phase a-c and delivers a-c current, or straight or reverse polarity d-c, to the welding arc. It features built-in high frequency equipment for the most exacting tungsten inert-gas metal-arc welding. Intensity is controlled by a stepless rheostat. Water and gas are controlled automatically by solenoid valves.

For details, circle No. 105 on Reader Information Card.

Guide Light for Welding

The Robbie Guide Light Co., Box 83, Smithport, Pa., has announced the availability of the Robbie guide light for welding

heads. One guide light is specifically recommended for submerged-arc welding guide problems and layout work alignment under drill or punch press.

The guide light operates on a 60-cycle 110 v transformer with a 6 v flashlight bulb.

For details, circle No. 106 on Reader Information Card.

New Electrode Line

The Stulz-Sickles Co., 929 Julia St., Elizabeth, N. J., recently disclosed that its new line of welding electrodes is being widely accepted and now placed on a full production basis at the Elizabeth, N. J., extrusion plant. The first four electrode types in the line are:

Stulz Manganese-XL (low hydrogen), an ac-dc austenitic 14% manganese-nickel electrode for high strength welds of dissimilar carbon and alloy steels, shock resistant build-up and low friction surfacing.

Stulz Universal Hardface, an all-purpose ac-dc electrode for heavy industry and mining where all combinations of abrasion, heavy impact and metal to metal wear occur. This rod reportedly reduces the need for a large variety of hard-surfacing electrodes.

Stulz Spray-rod, an ac-dc "spray-on" type rod for thin-layer hard-facing. Goes on fast, applying a hard smooth skin for protection of all steels against abrasion. Recommended for edge-facing where section is important.

Stulz Piercing Electrodes which will cut, gouge, channel and pierce any metal. They are said to have wide use in structural steel demolition for cutting out rivets and rusted bolts. They are also useful for joint preparation before welding, gouging out defective welds, piercing holes, veeing out cracks in cast iron and die blocks before welding, trimming risers and gates of castings. No special attachments required. All applications can be done with any standard d-c welding machine. Oxygen, air, special holders or auxiliary equipment are not required.

For details, circle No. 107 on Reader Information Card.

Valveless Torch

A new valveless welding torch suitable for production welding and brazing operations has just been made available by Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y. Greater economy in gas consumption and reduced operator fatigue is reported to result from a centralized control

system adapted to the Airco Style 725 valveless welding torch.

Specifically, the new unit differs from other standard dual-hose welding torches in that needle valves have been eliminated from the torch assembly. A "gas-mizer" is used in conjunction with the modified torch and flame adjustment is made at the regulators on the gas cylinder or pipeline station. The gas-mizer, located between the gas supply and the torch, closes off the fuel mixture whenever the torch is hung on the hanger arm hook. When the torch is picked up, the flow of gas is started again. The gas-mizer, which can be equipped with or without needle valves, has a pilot light to ignite the torch.

Adaptability of the Airco 725 Torch to mass operations is further enhanced by its light, well-balanced construction which reduces operator fatigue.

For details, circle No. 108 on Reader Information Card.

60-ton Welding Positioner

Aronson Machine Co., Inc., Arcade, N. Y., has announced what is reportedly the largest capacity powered elevation positioner available. This machine designated Model GE1200 has a weight capacity of 120,000 lb with the center of gravity location of the work 12 in. above the table of 12 in. off-center. Fifty-four in. of geared elevation at 15 ipm will reportedly lift full load at 90-deg tilt of the table. The geared elevation principle consists

of a 6-post elevator base having 10-in. OD by 1-in. wall seamless tubes with spur rack teeth for lift pinions. Each post has four concave guide rollers to maintain utmost rigidity and steadiness of the chassis while elevating. The cross-sectional column of the base measures 80 x 137½ in.

All elevator mechanisms including the posts are contained inside the chassis with nothing extending up above the top of the chassis to obstruct the turning of large weldments. A 30 hp brake-motor drives through six self-locking wormgear drives to affect elevation of the chassis.

For details, circle No. 109 on Reader Information Card.

Welded Round Stock Burr Removal

The first tools of their kind to accurately dress-off the burr in seconds from continuous lengths of butt welded round stock have been introduced by the Avery-Baird Co., 69 Coleman Ave., Cranford, N. J. The model "B" de burr tool (illustrated) occupies a floor space

22 x 18 in. and has a wide range of cutting speeds to handle all ferrous and non-ferrous stock ranging in diameter from 0.060 to 0.500 in. The model "A" de burr tool is a lightweight portable tool powered by an electric drill on air motor to handle wires 0.060 to 0.250-in. diam.

These tools are an important development enabling wire manufacturers and fabricators to butt weld round stock and dress-off the burr accurately, thereby improving the appearance and utility

of their product as well as making it possible to salvage short lengths which previously had to be scrapped.

For details, circle No. 110 on Reader Information Card.

Welding and Cutting Torch

The Harris Calorific Co., 5501 Cass Ave., Cleveland 2, Ohio, recently announced off-the-shelf availability of its new model 63-F heavy-duty, equal pressure oxyacetylene welding torch.

The new torch features high-temperature silicone "O" ring seals that permit fast, easy change of tip assemblies. The torch's universal-type mixer accommodates the

first 12 Harris tip sizes. Welding tip assemblies 15, 19 and 22 (No. 24 drill orifice), however, have individual mixers for maximum safety. Harris S-43-4 multiflame heating assembly also may be used with the new torch as well as a cutting attachment that cuts up to 6 in.

For details, circle No. 111 on Reader Information Card.

New 225-amp Welding Machine

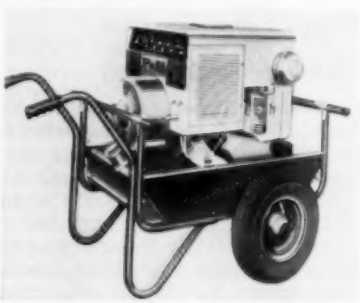
Lincoln Electric Co., Cleveland, Ohio, has developed a new 225-amp a-c transformer type arc welder offering metalworking shops output capacity and variety of electrode selection formerly available only in larger, higher priced industrial models. The new model, the company states, fills the need for welder performance between high capacity production welding equipment and small 180-amp shop machines. The new 225-amp machines will equip the user to perform "big" welding jobs eliminating the need to seek outside welding assistance.

The new Lincoln 225-amp arc welder is especially designed for convenience and versatility. Dial type current control provides quick adjustment and positive setting of the welder over an amperage range from 40 to 225 amp. Electrodes from the smallest to $^{3}/_{16}$ in. diam can be used to weld material of any thickness. Unusually stable arc characteristics for a welder of this capacity make possible the use of all types of electrode including E-6011, E-11018 low alloy-high tensile low hydrogen, E-308-16 stainless steel, and even more difficult to operate hardsurfacing types. Operation on 220 v, single phase power combined with compact, (2- x $1^{1}/_{2}$- x 1-ft case), lightweight, (136 lb), construction facilitates easy movement of the welder to the job when necessary.

For details circle No. 112 on Reader Information Card.

Double-duty Welding Machine

An engine-driven d-c welder that also serves as an a-c power plant is being manufactured by Harnischfeger Corp., 4444 W. National Ave., Milwaukee 46, Wis. Rated at 200 amp, 50% duty cycle, this



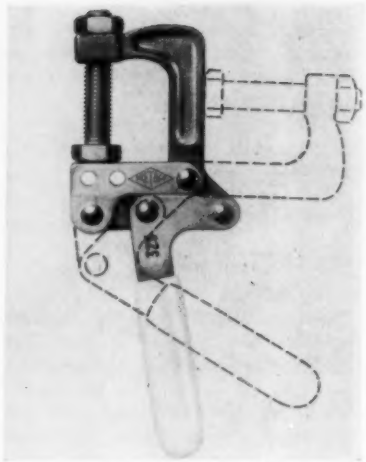
new unit delivers $3^{1}/_{2}$ kw, 120 v ac, 60 cycle current for lighting and electric tools.

Power is supplied by a two-cylinder, 4-cycle air-cooled gasoline engine of 12.8 hp at 2600 rpm, complete with 12-v electric starter.

For details, circle No. 113 on Reader Information Card.

Hold-down Toggle Clamp

Availability of a new hold-down medium-duty toggle clamp—Model 325—designed especially for attachment by welding the front or top of its base to the sides of conveyors or containers and the edges of lids or covers is announced by Detroit



Stamping Co., 330 Midland Ave., Detroit 3, Mich.

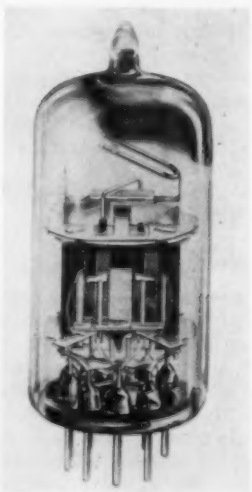
The new clamp, which weighs but 15 oz., has a holding pressure rated at 800 lb. Its jaw, or hold-down bar is made of forged alloy steel and moves 90 deg to clear working area. $^{17}/_{64}$-in. diam holes in the base allow for special mounting applications. De-Sta-Co Safety-Ease red plastic handle moves 50-deg for one-hand operation.

For details, circle No. 114 on Reader Information Card.

Miniature Pentode

The type 7788, a miniature 9-pin pentode incorporating two frame grids (control grid and screen grid) to attain a never-before-achieved transconductance of 50,000 micromhos, has been announced by Amperex Electronic Corp., 230 Duffy Ave., Hicksville, L. I., N. Y.

The 7788 is designed for use in broadband amplifying circuits such as radio and TV relay systems, coaxial telephone lines, radar equipment and oscilloscopes.



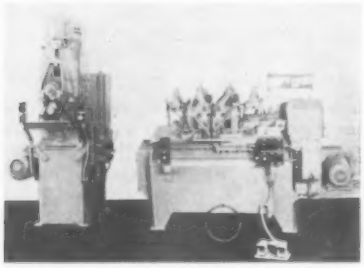
Immediately available in production quantities, the type 7788 has a figure of merit of 410 Mc, higher than any wide band amplifier tube available today. Equivalent noise resistance is 60 ohms, triode connected, and 100 ohms, pentode connected; a noise figure that is 50% to 100% better than similar tubes. Typical operating current is 35 ma, while average screen grid current is only 5 ma.

For details, circle No. 115 on Reader Information Card.

Welding, Trimming Machines

Swift Ohio Corp., Kenton, Ohio, announces new and improved tooling in production welding and flash trimming machines for welding and trimming automotive ring gears.

The Swift Ohio No. 25 flash welder is rated at 150 kva and is fully automatic in operation. The



Swift Ohio No. 0 oscillating flash trimmer is hydraulically operated. It is also fully automatic.

New and improved tooling, principal feature of both machines, are reported to result in greater production efficiency and economy. The flash welder clamp fixtures are designed to align both ends of the ring in a single motion. The tooling on the trimmer is adjustable over a range of sizes.

For details, circle No. 116 on Reader Information Card.

Cable Accessories

Cam-Lok Div., Empire Products, Inc., 9213 Blue Ash Rd., Cincinnati 2, Ohio, recently announced a complete line of cable connectors, panel and machine receptacles, and cable lugs to fit flexible power cable ranging in all sizes up to 750 MCM extra flexible. All are available either in waterproof, neoprene insulated styles, or in hard fiber insulated types for use where moisture is not a hazard.

Exclusive Cam-Lok "double cam" principle assures a positive-locking high pressure, low resistance connection that is quickly locked or

...AT AMPCO-BRāZ® 2FC

Here's a new flux-coated manganese bronze filler rod that gives you noticeably better braze-welding of steel, cast and malleable iron, copper and its alloys.

Ampco-Brāz 2FC has an extruded flux coating that is smooth and dense. Result: uniform, free-flowing deposits with excellent tinning action that produce high-strength joints.

Ampco-Brāz 2FC is also perfect for build-up application — on bearing, wear, and corrosion resistant surfaces on steel and cast iron parts. Overlay deposit hardness runs 80-110 BHN (500kg.)

So why not step up to Ampco-Brāz 2FC? Call your Ampco distributor today. Or, write for information — use coupon below.

And don't forget these other Ampco brazing products...

AMPCO-BRāZ No. 1
Low-fuming, high-strength, high nickel-silver rod for joining and overlay with the oxy-acetylene process. Bonds readily to copper-, iron-, and nickel-base metals.

AMPCO-BRāZ No. 4
Low-fuming, manganese bronze rod with nickel added. For brazing high-strength bronzes, brasses, steel, cast iron, and malleable iron with the oxy-acetylene process.

AMPCO-BRāZ FLUX No. 2
Saves time on general welding, cast-iron welding, and brazing. Provides dense, sound deposits. Easily removed. Non-fuming, non-toxic. Excellent wet-ability.

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AMPCO METAL, INC.
Dept. 196H, Milwaukee 1, Wis.

Send me complete information on the new Ampco-Brāz filler rods.

Name.....
Title.....
Company.....
Address.....
City..... Zone..... State.....
W-1&0

For details, circle No. 27 on Reader Information Card

disconnected by rotating a quarter of a turn, according to the manufacturer.

Where waterproof, neoprene insulation is desired, a low cost vulcanizing kit permits the user to make his own waterproof cable connections or repairs in the plant on his own cables in minutes with no special skill required. The kit includes thermostatically controlled 110 v vulcanizing press, uncured neoprene vulcanizing tape, etc.

For details, circle No. 117 on Reader Information Card.

Spark Lighter

Called the "Tripl-Flint-Lok" Safety Lighter by its manufacturer, Modern Engineering Co., 3401-15 Pine Blvd., St. Louis 3, Mo. The lighter has a trigger-operated safety lock which prevents flints from striking accidental sparks even when lighter is dropped. Flints can be locked before entering danger areas containing explosive concentrations of gases, dust or liquids. Lighter has replaceable, 3-flint unit, antisnag pocket guard and rustproof steel frame; lighter works in either hand.

For details, circle No. 118 on Reader Information Card.

High-production A-C Welding Machine

An industrial a-c welder, Type TC, has been developed by Westinghouse Electric Corp., Buffalo 5, N. Y., for high-production welding of mild and stainless steels. Designed to produce X-ray quality welds even when made in the vertical or overhead, the Westinghouse TC welder is reported to virtually eliminate arc blow, providing up to 20% production time savings. Built to operate from 230/460 v, 60 cycle supply, it has a nominant rating of 500 amp at 40 load volts, 60% duty cycle, 74 open circuit.

Exclusive features include easy arc striking, wide single range control, weatherized construction, and Westinghouse's unique single phase transactor for extended service life. All coils have 4 heavy-duty coatings of silicone fortified bonderite varnish for trouble-free operation and long life. Two or more units may be easily paralleled to obtain a current range equal to the sum of the setting for each unit. For extra heavy duty, Westinghouse WC-CM arc welders in ratings of 750, 1000, 1500 and 2000 amp are recommended.

For details, circle No. 119 on Reader Information Card.

Superconductor Material

A new superconductor material which reportedly offers no resistance to electrical current has been developed by Atomics International, a division of North American Aviation, Inc., P.O. Box 309, Canoga Park, Calif., under a research contract with the Atomic Energy Commission.

A wire which can be easily coiled has been drawn from the new superconductor. At liquid helium temperatures (−452° F) the wire has conducted 100,000 amp of electrical current per sq cm in a moderately high magnetic field (30,000 gauss). The performance of this wire may be roughly equated with operation of a household electrical appliance at about 100,000 from a normal-size (110 v) wall outlet.

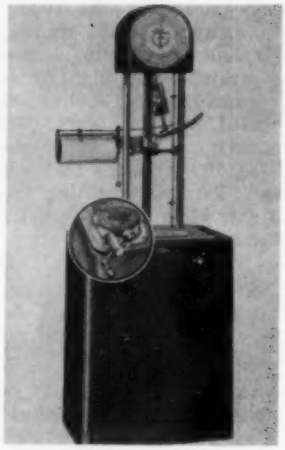
The new material is a cold-worked alloy made up of approximately three parts of niobium to one part of zirconium. The alloy is malleable and strong and can be made into wires, bars, strips and other shapes reportedly without losing its superconducting properties.

For details, circle No. 120 on Reader Information Card.

Precision Speed Control for Low-range Testers

A new remote speed control made by W. C. Dillon & Co., Inc., 14620 Keswick St., Van Nuys, Calif., permits greatly increased precision in presetting the tester to ASTM and Federal specifications. A simple turn of the new 360 deg segmented dial permits an infinite variance of the traveling crosshead speed from 0–20 ipm.

The new beveled edge of the dial provides a cross-hair register with the index line for fine positioning. Special counterbalanced Balcrank handle gives the technician a sensitive, positive feel while setting. New top-of-cabinet location assures clear viewing and reading.



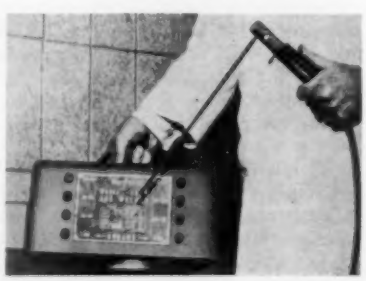
Dillon remote speed controls are now supplied for all Dillon low-range testers in the following 5 ranges: 0–10, 0–25, 0–50, 0–100, and 0–300 lb. Available also with a wide variety of gripping fixtures and accessories for testing materials for tensile, compression, transverse and shear.

For details, circle No. 121 on Reader Information Card.

Portable Arc Welder

A full 125 amp portable arc welder that weighs only 45 lb and measures but 12- x 16- x 9-in. high is now being marketed by Bren/Weld Sales, Inc., 5114 Third Ave., Brooklyn 20, N. Y. With ample capacity for any industrial maintenance or utility job, it is believed to have less than half the weight of any comparable welder. It has been thoroughly field tested.

The design of this Bren/Weld Model 125W also permits use in many small work production applications. It will weld anything from light sheet metal to $^1/_2$-in. plate. No special electrodes are required. Welding range is from 25 to 125 amp in 12 heat stages, and the unit operates from any



115 to 230 v a-c line, with 75 v open circuit for easy arc starting.

A major feature is the welder's fan-cooled transoidal transformer which keeps its heavy duty windings ventilated and supplies high efficiency with extremely low weight factor—particularly desirable for limited production jobs. Tape-wound core construction insures long life and quiet operation without the excessive buzzing usually produced by stacked laminations.

For details, circle No. 122 on Reader Information Card.

Natural Gas, Propane Cutting Torches

Harris Calorific Co., 5501 Cass Ave., Cleveland 2, Ohio, announces the availability of its "Universal" line of cutting torches that operate with equal efficiency on either natural gas supplied at city line

pressures, or on propane at cylinder pressures.

Identified by product numbers 62-2F (90-deg head) and 62-2AF (70-deg head), these torches are designed specifically for natural gas and propane, and to operate at any pressure from 3 oz up.

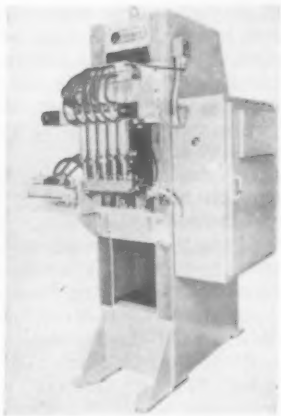
For details, circle No. 123 on Reader Information Card.

Universal Welding Machine Frames

Designed with basic universal frames in combination with other standard interchangeable components, manufactured by Kirkhof Mfg. Corp., 2450 Buchanan Ave., S.W., Grand Rapids 7, Mich., UF-56 and UF-96 series welders, offer special change-over economies. With simple tooling changes, they can be used year after year to meet a wide variety of resistance and arc-welding requirements, the manufacturer reports. Also, cost of the original equipment is often less than that of comparable equipment using specially designed frames.

The unit can be adapted for use as (1) a single spot welder, (2) a press projection welder, and (3) a combination spot projection press welder.

Predrilled front mounting plates on the UF-56 frame facilitate the movement of top and bottom platens for fast change-over to new



job set-ups. A wide range of throat depths, welding press heads and electrode and die holders can be used. Two sizes of universal frames are available: the UF-56 pictured and the UF-96 which will accommodate up to 22 fixture-type guns or up to three projection press heads and projection stations.

For details, circle No. 124 on Reader Information Card.

Precision Form-rolled Titanium

Titanium, form rolled to precise tolerances, is now available from Engelhard Industries' D. E. Makepeace Div., Plainville, Mass.

Tolerances to ±0.001 and controlled surface finishes down to 8 microinches can be provided by the division's Form Roll Dept. in a variety of shapes of titanium as well as for a wide range of other metals such as brass, the 400 series of stainless steel, Monel, Inconel, Waspaloy, and Greek Ascoloy.

The elimination of all or most of the normal machining operations and resultant scrap associated with contoured stock is among the advantages offered by the Makepeace process, which has been utilized

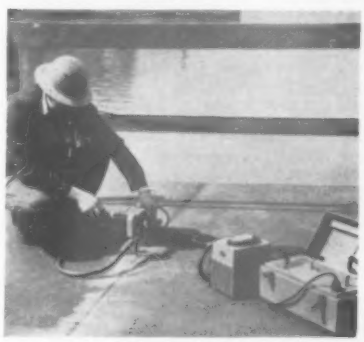
for blades and vanes in jet engines, steam turbines, nuclear fuel elements and rolled and butt-welded rings.

For details, circle No. 125 on Reader Information Card.

Magnetic Tester

A one-man portable magnetic particle testing unit that produces 1000 amp of ac or half-wave dc to detect surface and sub-surface flaws has been introduced by Picker X-Ray Corp., White Plains, N. Y.

"The new unit, the portable ferroscope, is ideal in industries such as marine construction, petroleum, aircraft, bridge building, welding and wherever true portability and high power are desired,"



said John W. Leask, industrial sales manager of Picker. "It is significantly lighter than any unit with so much power, and small enough to fit through openings 18-in. wide."

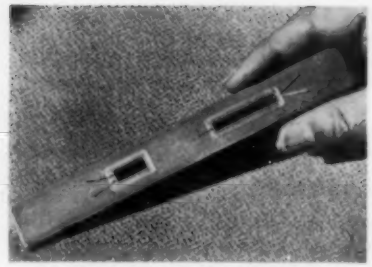
The portable ferroscope can be used with prods or coils for maximum flexibility. Prods can be fastened for one-hand operation, or used separately. The unit is fan-cooled and offers five-place ampere selector and safety limit switches. Its dry-type silicon rectifiers are housed in aluminum for lower weight and temperatures.

For details, circle No. 126 on Reader Information Card.

Stabilized Strain Gages

A new line of weldable strain gages—reported to be the first of their kind to provide electrical stability from cryogenic through 750-deg temperatures—has been developed by Electronics & Instrumentation Div. of Baldwin-Lima-Hamilton Corp., 42 Fourth Ave., Waltham 54, Mass.

Small and rugged, the gages afford ease of installation, operation over an extremely wide range of temperatures, and high linearity over the complete temperature range, according to the manufacturer.



They are available for such applications as stress and pressure testing of nuclear reactor power loops, liquefied gas pressure vessels and systems, aircraft and missile components and engines, plus heavy construction and machinery testing where shutdown time is at a premium.

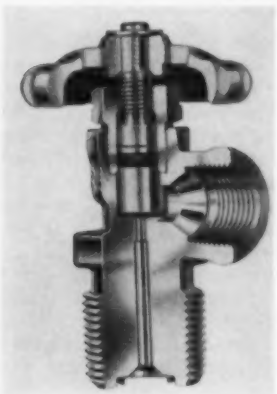
The new gages are fully stabilized by heat treating—cutting over-all installation time from days or hours to minutes through elimination of the need for curing and stabilizing after the gages are installed on a testpiece, it is reported.

For details, circle No. 127 on Reader Information Card.

Acetylene Cylinder Valve

The new RegO 600 Series, "O"-ring type acetylene cylinder valve, manufactured by RegO Div., Bastian-Blessing Co., 4201 W. Peterson Ave., Chicago 46, Ill., is said to offer a reduction of maintenance costs and an ease of operation hitherto unrealized with the traditional packed type, wrench-operated, acetylene cylinder valve.

This thoroughly field tested "O"-ring design with an umbrella-type wheel handle reportedly promotes smooth operation without use of a valve wrench which may easily be mislaid. A leak-tight stem seal is formed by the wiping action of the acetylene and acetone compatible "O"-ring against the valve bonnet. Because this wiping action is effective against the easily replaceable bonnet, only the valve bonnet (not the valve body) need be replaced if its wiping surface is damaged. The handwheel's umbrella design will not collect water and permits a ready inspection of the valve stem for leakage, at any time.



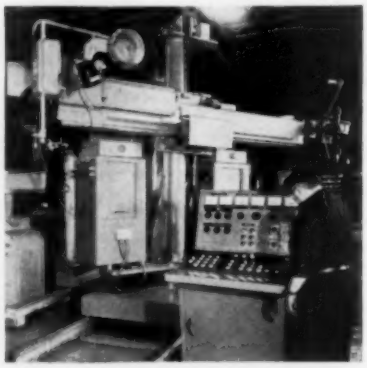
Positive shutoff with minimum effort is assured by the nylon-valve seat disc. Other safety features include the left hand bonnet nut which prevents the accidental backing-out of the valve trim assembly and a backseat feature providing a secondary stem seal.

For details, circle No. 128 on Reader Information Card.

Lab Welding Unit

C. B. Herrick Manufacturing Corp., 2000 Center St., Cleveland 13, Ohio, has developed a complete automatic welding facility for laboratory use which is recommended for research, experimental and developmental projects.

It consists of a heavy duty (minimum deflection) ram type manipulator mounted on variable speed travel carriage, airline longitudinal seam welding fixture, airline circumferential welding fixture,



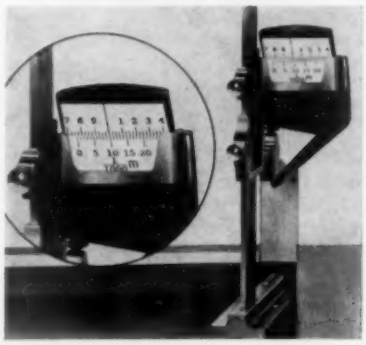
complete welding equipment for metal inert gas, tungsten inert gas, and submerged-arc welding; six channel recorder and control console.

The operator has complete automatic control of all the components. The welding head can be positioned and run onto the side beam track which is part of the longitudinal fixture. The manipulator provides 6 ft of vertical adjustment, 9 ft of horizontal variable speed ram travel and 360 deg rotation. The welding heads at either end of the ram may be positioned over the seamer, the circumferential fixture or turning rolls which are lined up along the track. Any weldable material can be handled in thicknesses ranging from 0.002 in. to heavy plate.

For details, circle No. 129 on Reader Information Card.

Gage Magnifier

A new magnifying instrument, the "Mark V," is now being introduced for use on all precision machine tools equipped with a height gage. Developed and manufactured by Pan Technics, Inc., 1230 Pan Technics Bldg., Enanitas, Calif., the key feature of the "Mark V," is time-saving operation —readings can be made directly from the magnifying lens, without



removing the gage, turning it horizontally, or making any other adjustments. It also allows adjustments to be made in working position. On milling machines, jig borers, radial drills and other equipment where it has been used, this "direct reading" has reportedly reduced reading times up to 60%. The attachment technique is designed to save operator time since it attaches to the height gage with magnets instead of clamps, screws, etc.

For details, circle No. 130 on Reader Information Card.

Welding Machine for Farm Maintenance

A compact, low-cost general utility welder for farm maintenance use is available from the Westingarc Dept. of Westinghouse Electric Corp., Buffalo 5, N. Y. This general utility welder is designed for rough farm use and long service life.

It has many of the features of Westinghouse industrial welders and can be used for repairing tanks, troughs and trailers, and for hard-surfacing plows, bailers and loaders. Hard forming is accomplished simply by using a carbon arc. The welder will cut mild and stainless steels, cast iron, aluminum and other sheet metals.

Welding current can be set at any value within the machine's range without moving any switches or changing cables or taps. A quick switch converts the welder from ac to dc. Range is 25 to

250 amp ac, 20 to 200 amp dc. Four heavy duty swivel-type casters make it readily portable.

For details, circle No. 131 on Reader Information Card.

New Trigger Tube

Amperex Electronic Corp., 230 Duffy Ave., Hicksville, L. I., N. Y., announces the Type 7711/Z71U, a subminiature gas-filled, cold cathode trigger tube especially designed to be used as an inertialess switch and counter in automatic telephone exchangers and for timers.

Being an inertialess device, use of the 7711 makes it possible to attain very high speeds in making connections, enabling the telephone

exchanges to handle more calls more quickly than would otherwise be possible. A further advantage is that, unlike relays, these tubes need no maintenance. Moreover, with a starter transfer current of only 40 μa, 7711 is ideally suited for use with semiconductor diodes and transistors. Circuits have been designed that make the tubes fully interchangeable.

For details, circle No. 132 on Reader Information Card.

New Electrode Packaging

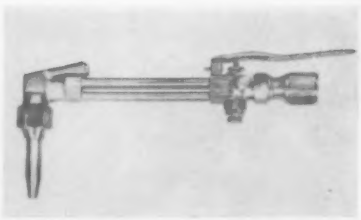
A new 5 lb package for Nickel-arc electrodes to meet the job needs of a majority of users for smaller quantities of electrodes is announced by Alloy Rods Co., P.O. Box 1828, York, Pa. These electrodes are used for welding cast iron. Six moisture barrier tubes are packed

in a standard carton. The new package is for electrodes $^1/_8$-in. diam and larger.

For details, circle No. 134 on Reader Information Card.

New Medium Pressure Cutting Attachment

The Harris Calorific Co., 5501 Cass Ave., Cleveland 2, Ohio, recently announced a new Model 73 medium pressure cutting attachment that will cut up to 6 in. and can be used with any one of three Harris Welding Torches: Nos. 63 and 43 heavy-duty welding torches, also the No. 18-2 heavy-duty automatic welding torch.



The new cutting attachment employs the head-mix principle and is said to be virtually impossible to back-fire. Double silicone "O" ring seals are used for positive, finger-tight union.

For details, circle No. 135 on Reader Information Card.

Aluminum-silicon-copper Alloy

Light-weight, wear and corrosion resistant aluminum-silicon-copper extrusions for high-production screw machine work are being produced by Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 1, Wis.

The new alloy—Ampcoloy 405—is initially available in two extruded shapes, solid round and hexagon, and is intended for use as valve stems, valve seats, gears, marine hardware, pole line hardware, bushings, bearings and cams.

Ampcoloy 405 is nonmagnetic; it will hot forge and is free machining. The alloy will also withstand relatively high temperatures. Produced wholly from virgin metals to closely controlled composition limits, Ampcoloy 405 is reported to be the highest quality product of its type available.

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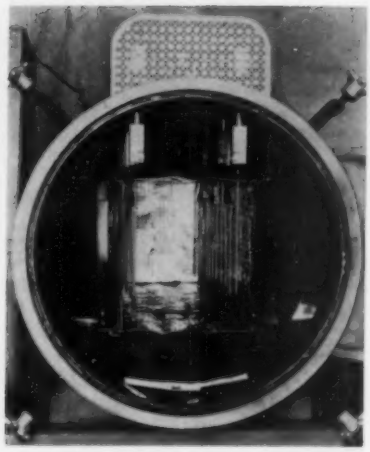


(4500° F) at 1 x 10−5 mm of mercury pressure has been developed by Vacuum Specialties, Inc., Somerville, Mass., subsidiary of the Geophysics Corp. of America.

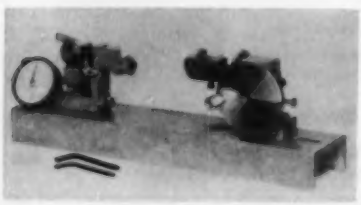
Designed for high temperature materials research, development and production programs in the electronics, space and nuclear fields, the new line consists of twenty-seven models in nine different sizes. The units employ internally heated hot zones which may be arranged either vertically or horizontally. Sizes range from 60 to 2700 cu in.

For details, circle No. 137 on Reader Information Card.

Weld Strength Testers

The addition of weld joint tensile testers to its line of electronic welding equipment has been announced by the Vacuum Tube Products Div. of Hughes Aircraft Co., 2020 Short St., Oceanside, Calif. These portable units find application in the development of weld schedules used in high density electronic component packaging as well as in statistical quality control of production welding.

The units are available in two models; the VTA-46, having a testing range of 0–50 lb, and the VTA-47 with a 0–100 lb range. Both models feature a load indicator which holds the maximum specimen pull until reset. A one to one mechanical adjustment of the load jaws makes possible quick set-ups, but actual loading is applied through a 100–1 reduction wheel. Other features of the units are a jeweled meter movement, interchangeable jaws and antiback-lash provisions to prevent surge readings, at the breaking point.



For details, circle No. 138 on Reader Information Card.

Ther-Monic Annealing Unit

Induction Heating Corp., Brooklyn, N. Y., has developed a Ther-Monic unit for automatically annealing auto brackets. Special tooling was installed in a Ther-Monic single-position, all-steel heavy-gage modular table. This unit contains all of the control circuitry and a Ther-Monic RF variable ratio output transformer which reduces workcoils to a safe, low-voltage operation.

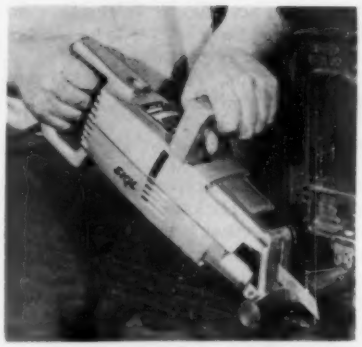
The work table and coil automatically anneals four sections of two differently-sized plates at a production rate of $3\frac{1}{2}$ sec per plate using a 25 kw induction heating generator, according to the manufacturer.

For details, circle No. 139 on Reader Information Card.

Metal Cutting Saw

Skil Corp., 5033 Elston Ave., Chicago 30, Ill., has announced a new metal cutting model which the company reports will cut all metals, including stainless steel. In addition to the new metal cutting saw, the company also offers a new improved version of their 2-speed, all-purpose Model 700. According to the company, this combination of two reciprocating saws will cut virtually any material.

The all new tool is the Model 701 Recipro Saw. It has two speeds —1000 and 1400 strokes per min— for cutting different gages and densities of metal. The low speed is for stainless steel. other hard



alloys, cast iron, any hard abrasive material. The high speed is recommended for cutting mild steel and nonferrous metals.

An extra heavy-duty tool, it is for use by truck body plants, welding shops, plumbers, contractors, electricians, steel warehouses, metal fabricators and other metalworking users. It is excellent for any metal cutting job requiring a portable tool for cut-off or pattern work.

For details, circle No. 140 on Reader Information Card.

Angle Beam Transducers

An entirely new group of angle-beam transducers, for use with ultrasonic flaw-detection equipment, has been announced by Branson Instruments, Inc., 40 Brown House Rd., Stamford, Conn. Designed primarily for the company's Sonoray flaw detector, the transducers may also be used successfully with similar ultrasonic instruments.

Angle-beam transducers find many applications in industry, where hidden flaws, voids, porosities or discontinuities in metals and other hard materials must be detected, even when access to only one surface is possible. Although, in many instances, straight-beam transducers are sufficient, angle-beam transducers offer certain advantages not otherwise obtainable.

They often detect defects which might be missed by a straight beam; they avoid multiple back reflections in thin sections; they will more quickly scan large areas; and they may be used where the shape of the component prevents direct contact with a straight-beam transducer.

Branson has three new types of angle-beam transducers available, each type offering a number of variations in wedge angle as well as transducer size and operating frequency. All incorporate high-sensitivity Type Z crystals, a lucite wedge, and a cable with BNC quick-disconnect fitting.

For details, circle No. 141 on Reader Information Card.

New Galvanized Sheet

A new differentially zinc-coated sheet, designated Armco Zincgrip DC and featuring a corrosion-resistant, hot-dip zinc coating on one surface and a smooth spangle-free finish providing an excellent base for high luster body finishes on the other, will be introduced by Armco Steel Corp., Middletown, Ohio, at the Truck Body and Equipment Show in Chicago, October 24–26th.

The new sheet combines, for the first time, paintability with good spot welding characteristics while providing corrosion protection where it is needed.

By coating only one surface with a standard weight of zinc, the welding characteristics of the sheet were sharply improved. Twice the number of spot welds possible on regular galvanized sheet reportedly can be made on Zincgrip DC before welding tips applied to the nonspangled side had to be redressed.

For details, circle No. 145 on Reader Information Card.

Light and Power Cord Reel

New reels available from Cordomatic Reels, 17th & Indiana Ave., Philadelphia 32, Pa., are designed to eliminate tangled drop cords in industrial operations of many types; unnecessary operating costs are cut down, shop safety increased. There is a reel for every purpose: heavy maintenance and production work, safety functions.

For details, circle No. 146 on Reader Information Card.

New Desk and Table-top Drafting Machine

A new compact, desk and table-top drafting machine to provide fast and accurate finished drawings of complex diagrams was recently introduced by the Keuffel & Esser Co., Third and Adam Sts., Hoboken, N. J.

Called the Paragon Jr., the new unit is for use by the engineer, architect or draftsman who requires a board for part-time office or home use; the student of drafting (for classroom use) and others who have only an occasional need for a drafting board.

Combining the drawing capabilities of a T-square, straight edge, triangle, scale and protractor, the Paragon Jr. features controls that permit one-hand operation. A simple bracket assembly facilitates temporary or permanent mounting on almost any desk, board or table.

Features include a control head with full 360 deg indexing and automatic 15 deg stops, a rapid release for intermediate settings, and a convenient lock for intermediate setting of the protractor and vernier. Other features include: an 1800 baseline adjustment facilitating fast setting for offset drafting, easily twisted arms that move in any direction and can be lifted over objects on the board or desk and returned to exactly the same setting, and precision bearings which control the smooth easy movement of the machine over the drawing board.

For details, circle No. 147 on Reader Information Card.

Electron Beam Systems

GVC Electron Heating Corp., 81 Hicks Ave., Medford 55, Mass., has recently introduced its Series LB-100 Electron Beam Systems. The series emcompasses a complete line of systems including guns, power supplies and controls in various ratings. These systems cover a range from 3 kw at 10,000 v to 9 kw at 30,000 v. The systems are complete and provide magnetic deflection of the beam over a 3-in. sq area, pulsing of the beam energy, regulation of the emission beam over a wide range and variable focus and focal length.

They are designed for adaption on programmed automatic operations by utilizing the deflection feature to produce desired welding or etching patterns on a workpiece.

The LB-100 Systems can reportedly be used for a wide range of heating and melting applications including welding, melting of refractory metals and ceramics, refining, glazing, electronic interconnecting, evaporation, etching, surface conditioning, encapsulation, microcircuit fabrication, brazing and as a general laboratory production devile capable of readily attaining temperatures in excess of 6200° F.

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TEC and TEC-Z

...How to choose between a soft solder and a brazing alloy

Handy & Harman provides *two* alloys that fit between "something stronger than the average soft solder but not as strong as a silver-brazing alloy." They are named TEC and TEC-Z and their flow points are intermediate between soft solders and silver-brazing alloys. Joints made by these alloys are strong in straight tension or shear. For instance, butt joints of cold-worked copper can be made having a tensile strength of about 25,000 psi. This is approximately 10,000 psi. more than can be obtained with tin-lead soft solders. TEC joints retain their strength at elevated temperatures much better than the tin-lead soft solders. As shown in the table below, the strength of the solder itself at 425° F is about the same as a 50% tin–50% lead solder at room temperature in short-time tensile tests.

Applications—One example is a thermostatic bellows where the operating temperature is too high for soft solders (tin-lead), yet requires a joining medium which will not anneal the bellows. Another use is gun parts which require joint strength at higher than soft-solder operating temperatures *plus* corrosion resistance to solutions used in cleaning and blackening. Also for lamp bulb bases operating at approximately 350°-500° F. Automotive applications and heat exchangers. TEC conforms to Government Specifications Mil-S-19234 (Nord); both TEC and TEC-Z are available in sheet, wire, powder, and preforms to specifications.

NOMINAL COMPOSITIONS

	TEC	TEC-Z
Silver	5% plus or minus 0.5%	5% plus or minus 0.5%
Zinc	—	16.6% plus or minus 0.5%
Cadmium	95% plus or minus 0.5%	78.4% plus or minus 0.5%

PHYSICAL PROPERTIES

	TEC	TEC-Z
Color	White	White
Melting Point	640° F	480° F
Flow Point	740° F	600° F
Density (Troy oz/cu in.)	4.60	4.53
Electrical Conductivity (Cu=100)	22.0%	20.6%
Electrical Resistivity (Microhm-cm)	7.9	8.4

STRENGTH COMPARISON TEC vs. Pb-SN

	TENSILE STRENGTH LBS/SQ IN. TEC	TENSILE STRENGTH LBS/SQ IN. Pb-SN
ROOM	16,400	2,500
300° F	4,400	650
425° F	2,600	Melts
500° F	1,700	

The information and data on this page are available in our Handy Alloy Data Sheet. Ask for "TEC." Handy & Harman, 850 Third Ave., New York 22, N. Y.

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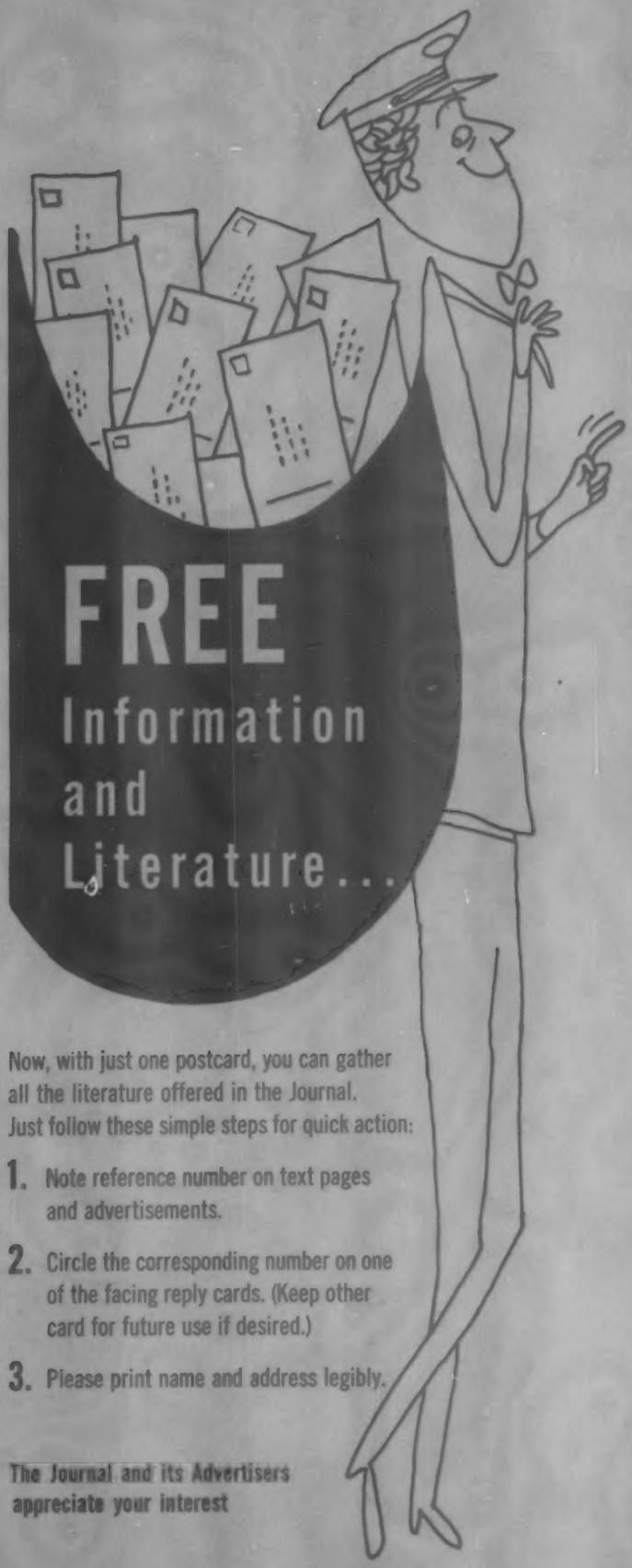

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Welding Research

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SUPPLEMENT TO THE WELDING JOURNAL, AUGUST 1961

Flux and Filler-Wire Developments for Submerged-Arc Welding HY-80 Steel

A new flux raises weld metal impact properties while lowering oxygen and inclusion contents, and a new filler wire produces weld metal with notch toughness over 40 ft-lb at −80° F in both as-welded and stress-relieved states

BY W. J. LEWIS, G. E. FAULKNER AND P. J. RIEPPEL

SUMMARY. Under a program conducted for the Bureau of Ships at Battelle Memorial Institute, a flux and filler wire were developed for submerged-arc welding submarine hulls. Welds made with this flux and filler wire have nil-ductility temperatures of −150° F and yield strengths over 90,000 psi in both the as-welded and stress-relieved conditions. These properties exceed those specified by the Navy.

This work was done to develop procedures for welding submarine hulls with the submerged-arc welding process. Modern submarine hulls must be able to withstand severe impact loading at operating temperatures. The steel (HY-80) used in hull construction has excellent toughness and can withstand severe impact loading. Now, submarine hulls are welded manually. The joint properties of the manual welds are satisfactory, but they cost more than mechanized welds. The inert-gas-shielded and submerged-arc processes were considered as possible mechanized processes for welding submarine hulls. Inert-gas welding is limited, because the wind in the shipyard blows the gas away from the arc, causing poor joint properties. The use of submerged-arc welding is limited, because the weld metals made with standard filler wires and fluxes do not have the required impact properties.

In this program, a new flux was developed to lower the oxygen and inclusion contents of the weld metals and raise their impact properties. The new flux was developed from studies of 75 experimental fluxes that had the following range of compositions: SiO_2—18 to 38%, MnO—0 to 20%, Al_2O_3—0 to 20%, CaO—0 to 50%, Na_2O—0 to 12%, K_2O—0.35 to 10.35%, TiO_2—0 to 20% and CaF_2—7 to 27%. The fluxes were evaluated on the basis of weld-metal impact properties.

Submerged-arc welds deposited with many of the experimental fluxes had higher notch toughness than weld metals deposited with commercial fluxes. In addition, some of these weld metals had better notch toughness than weld metals deposited by inert-gas-shielded metal-arc welding. Weld metals deposited with some of the best fluxes and a commercial filler wire had vee-notch Charpy-impact energy values above 50 ft-lb at −80° F.

In addition to the flux developments, filler wires were studied to develop a wire that would produce welds with satisfactory properties in both the as-welded and stress-relieved conditions. A filler wire was developed and, when used with one of the experimental fluxes, produced weld metals with notch toughness over 40 ft-lb at −80° F in both the as-welded and stress-relieved conditions. In addition, the weld metals made with this experimental flux and filler-wire combination had yield strengths over 90,000 psi in both conditions.

Drop-weight tests were made on specimens welded with the experimental flux and filler wire to determine nil-ductility temperature. The nil-ductility temperature of welds made with the experimental wire and flux was −150° F. This result compares with the nil-ductility temperature of the HY-80 base material (−100 to −200° F).

The authors are with the Metals Joining Div., Battelle Memorial Institute, Columbus, Ohio, where W. J. LEWIS is Project Leader, G. E. FAULKNER is Assistant Chief and P. J. RIEPPEL is Chief.

Paper presented at the AWS 42nd Annual Meeting held in New York, N. Y., April 17-21, 1961

Background

Modern submarine hulls must be able to withstand severe impact loading at all operating temperatures. Such performance is obtained by using selected steels and welding procedures to obtain ductile behavior in the hulls, even in the presence of sharp notches. Submarine hulls are made from HY-80 steel. HY-80 is a low-alloy, high-strength steel that has a minimum yield strength of 80,000 psi. This steel has excellent notch-toughness properties (50 ft-lb vee-notch Charpy impact energy at −120° F). In conjunction with this notch-

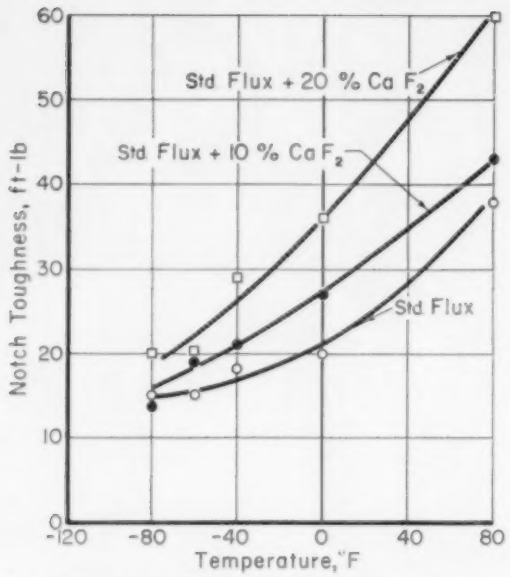

Fig. 1—Effects of additions of calcium fluoride to standard flux on notched-bar properties of submerged-arc weld metals

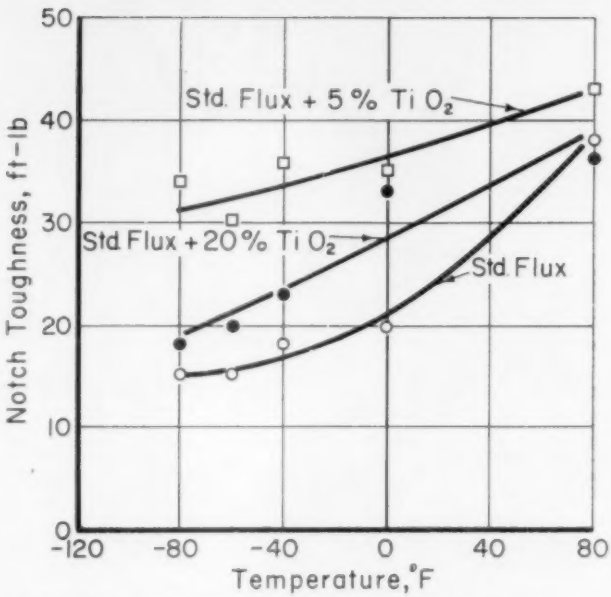

Fig. 2—Effects of titanium dioxide additions to standard flux on notched-bar properties of submerged-arc weld metals

tough steel, manual welding procedures that produce notch-tough weld metals and heat-affected zones are used.

Many of the joints in hull construction are suitable for automatic welding with processes such as submerged-arc welding. The use of the submerged-arc process would be much cheaper than manual welding. However, the notch toughness of submerged-arc welds made with standard filler wires and fluxes are not satisfactory for submarine-hull construction.

This study was conducted to develop ways for making submerged-arc welds that would be satisfactory for submarine-hull construction. The specific objectives were to obtain submerged-arc weld metals with yield strengths of at least 80,000 psi and vee-notch Charpy-impact energies of 20 ft-lb at −100° F or a nil-ductility temperature of −100° F in both the as-welded and stress-relieved conditions.

Previously, an attempt had been made to improve the notch-toughness properties of submerged-arc welds by changing filler-wire composition. Surprisingly, this was not successful even though the filler-wire compositions matched those used in other welding processes to produce satisfactory welds. Studies were then made to see why submerged-arc welds had lower notch toughness than inert-gas-shielded welds. Submerged-arc welds were found to contain: (1) more inclusions, (2) more oxygen and (3) more silicon than inert-gas-shielded welds. Obviously, the flux was causing the poor toughness properties. A program was thus set up to develop better fluxes.

Preliminary Flux Studies

Previously,[1] it was found that submerged-arc weld metals had high oxygen contents and many inclusions. An attempt was made to lower the oxygen and inclusion contents by modifying a standard flux. The standard flux was modified with single additions* of C, CaF_2, $CaCO_3$, MnO_2 and TiO_2. Submerged-arc welds were made in $^1/_2$-in. thick plate using the modified fluxes and an experimental filler wire (0.08 C, 1.18 Mn, 0.26 Si, 1.91 Ni and 0.57 Mo).

CaF_2 and TiO_2 were the only additions that proved to be beneficial on the basis of weld-metal notch toughness. The notch toughness increased with increasing CaF_2 content (Fig. 1). With a 20% addition of CaF_2, the weld-metal notch toughness was 20 ft-lb higher at room temperature and 5 ft-lb higher at −80° F than welds made with the standard flux.

The notch toughness of the welds made with fluxes containing additions of TiO_2 was slightly better at room temperature (Fig. 2) and much better at subzero temperatures than the toughness of welds made with the standard commercial flux. The 5% addition of TiO_2 appeared to be more beneficial than the 20% addition. With the 5% addition, the weld-metal notch toughness was 20 ft-lb higher at room temperature and 34 ft-lb higher at −80° F than the notch toughness of welds made with the standard flux.

Table 1—Oxygen Contents of Submerged-arc Welds Made with Various Fluxes

Flux	Oxygen content, %
Standard	0.096
Standard + 5% TiO_2	0.081
Standard + 20% CaF_2	0.045

The welds made with the modified fluxes were analyzed and examined metallographically to see what changes occurred. The oxygen contents of the welds made with the modified fluxes were lower than those of welds made with the standard flux (Table 1). Also, fewer and smaller silicate inclusions were found in the welds made with the modified fluxes than in the welds made with the standard flux.

These improvements indicated that studies were needed to develop a new fused flux.

* Details of flux and wire preparation, welding and testing procedures are given in the Appendix A.

Table 2—Composition Range of Fluxes Studied

	Composition, %					
	SiO_2	MnO	FeO	Al_2O_3	CaO	MnO
Standard flux[a]	38	7.2	1.6	10 6	25.3	12 1
Range of intended compositions studied in this program	18–38	0–20	...	0–20	0–50	0–20
	Na_2O	K_2O	F	TiO_2	CaF_2	
Standard flux[a]	2.2	0.35	1.7	0.6	...	
Range of intended compositions studied in this program	0–12.2	0.35–10.35	...	0–20	7–27	

[a] Reported composition.

Table 3—Notch Toughness of Submerged-arc Welds Made with Several Experimental Fluxes

	Notch toughness at indicated temperature, ft-lb				
Flux	RT	0° F	−40° F	−60° F	−80° F
19	56	48	47	45	35
16	55	42	41	40	33
23	55	50	43	40	29
18	49	45	40	34	29
25	49	44	40	27	28

Fused Flux Developments

Because of the success obtained in the preliminary studies on adding CaF_2 and TiO_2 to the standard commercial flux, further flux studies were deemed necessary. However, it was believed that these studies should be made with fused fluxes. A number of experimental fluxes were fused. Initially, the compositions of the fluxes were based on the reported composition of the standard commercial flux (Table 2). The original composition was varied over a wide range. The variations were made in two groups. First, the TiO_2, SiO_2 and CaF_2 contents were varied. After the best combination of TiO_2, SiO_2 and CaF_2 was developed, the MnO, Al_2O_3, MgO and CaO contents were varied.

All of the experimental fluxes were used to make submerged-arc welds in 1/2-in. thick HY-80 steel plate with 3/32-in. diam commercial filler wire. The weld metals were evaluated on the basis of Charpy vee-notch-thoughness properties

Effects of Varying the TiO_2, SiO_2 and CaF_2 Compositions

Fluxes that contained 7 to 27% CaF_2, 18 to 38% SiO_2 and 0 to 20% TiO_2 were fused. The actual compositions that were studied are shown in Fig. 3 where points represent the compositions studied and numbers represent the flux numbers. The CaF_2, SiO_2 and TiO_2 contents consisted of 45% of the total flux composition. The remainder of the flux consisted of: Na_2O—2.2%, K_2O—0.35%, MgO—12.1%, CaO—20.3%, MnO—7.2% and Al_2O_3—10.6%.

The welds made with these fluxes had the same appearance as those made with the standard commercial flux. Also, no difficulties were found in slag removal. Weld-metal notch toughness was better with some fluxes than with others. The best results were obtained with a flux containing about 5% TiO_2, 20% CaF_2 and 20% SiO_2 (Flux 19). A comparison of the notch toughness of welds made with Flux 19 and the standard commercial flux is shown in Fig. 4. The notch toughness of welds made with Flux 19 was 20 ft-lb higher at all testing temperatures than that of welds made with the standard flux. Welds made with fluxes that contained 18 to 22% SiO_2 also had good notch toughness (Table 3). Hower, welds made with experimental fluxes containing higher silica and titania had poor notch toughness.

Effects of Varying the MgO, CaO, MnO and Al_2O_3 Compositions

Variations of Flux 19 were next fused. The Al_2O_3, MgO and MnO contents were varied from 0 to 20% and the CaO contents were varied from 0 to 40%. In making all of these fluxes, the Na_2O, K_2O, SiO_2, TiO_2 and CaF_2 contents were held constant. The intended compositions of the fluxes are shown in Table 4.

The notch toughness of welds made with several of the new fluxes was better than that of welds made with Flux 19. The best weld-metal impact properties were found with Flux 47. Figure 5 shows a comparison of the notch toughness of welds made with Fluxes 47, 19 and the standard commercial flux. The notch toughness of the welds made with Flux 47 are about 35 ft-lb higher than the notch toughness of welds made with the commercial flux. Also, welds made with several of the other fluxes had good impact properties (Fig. 6).

The weld metals obtained with the fluxes were examined metallographically and analyzed. The

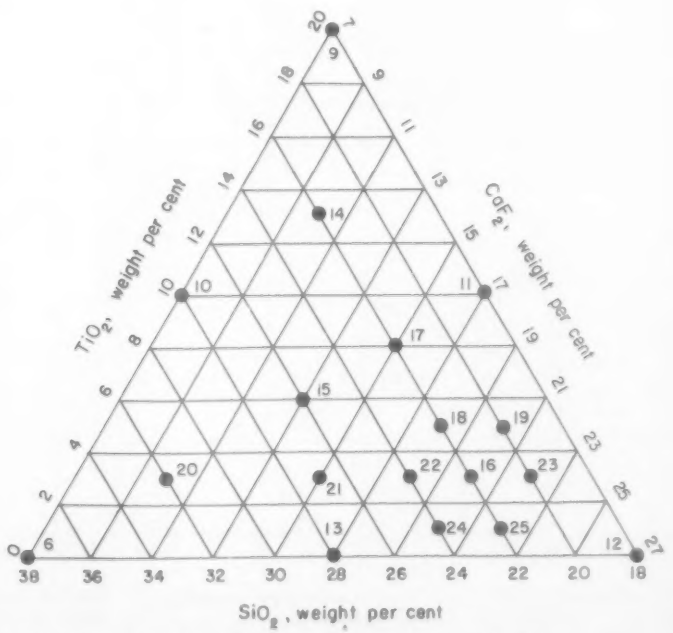

Fig. 3—Calcium fluoride, titania and silica compositions studied

weld metals made with the better experimental fluxes had fewer and smaller inclusions than the weld metals made with the standard flux (Fig. 7). Also, the oxygen contents of the weld metals differed. The oxygen content of welds made with Flux 47 was 450 ppm compared with 960 ppm for the weld made with the standard flux.

The relationships between flux composition and oxygen and inclusion content are associated with the chemical reactions that occur during welding. All of the reactions occur in a very short time over a wide temperature range, because the temperature of the weld pool is initially very high (7000 to 10,000° F) and rapidly changes in cooling down. The exact nature of these reactions is not known, because they occur at conditions that are far from equilibrium. However, the solubility of oxygen increases as the weld pool is heated and decreases as the weld pool cools; hence the reactions tend to be oxidizing in the hot part of the welding cycle and tend to be deoxidizing as the weld pool cools.

The prime role of the flux is to minimize or prevent oxidation of the weld pool. With all of the fluxes, the weld is adequately protected from oxidation by the atmosphere. However, all of the fluxes contain metal oxides, and some of these oxides react with the molten metal and dissolve during the welding cycle. With high silica fluxes, SiO_2 would be reduced by iron at the highest temperature of the weld pool. At these high temperatures, both O_2 and Si would dissolve in the molten steel. The solubility of oxygen in iron is high at welding temperatures, about 0.23% at 3000° F and about 0.17% at the melting point. However, the solubility of oxygen in solid iron is practically nil (0.003 ± 0.003% at 2363 to 2516° F); thus when the liquid metal freezes, the oxygen must precipitate.[3]

It is theorized that, during submerged-arc welding, the molten flux reacts with the molten weld metal so that some oxygen is dissolved in the liquid metal. As soon as the weld pool starts to cool, the slag and precipitated oxides rise to the top of the weld. During cooling, the solubility of oxygen in iron decreases so that oxygen is precipitated and probably reacts as follows:

$$2FeO + Si \rightarrow SiO_2 + 2Fe$$
$$FeO + Mn \rightarrow MnO + Fe$$
$$SiO_2 + 2Mn \rightarrow 2MnO + Si$$

Some of the oxides obtained from these reactions levitate to the top of the weld, but undoubtedly some are trapped in the form of inclusions.

In this study, belief was that, in changing flux composition, the stability of the fluxes was increased so that the amount of oxygen and silicon available from flux reactions with the weld pool was lowered. As a result, less oxygen was available to precipitate during cooling and solidification of the weld-metal pool. In addition, less oxides were believed to be trapped in the weld metal, because the diffusion rates of the slag should be increased because the new flux was more fluid than the standard flux.[4]

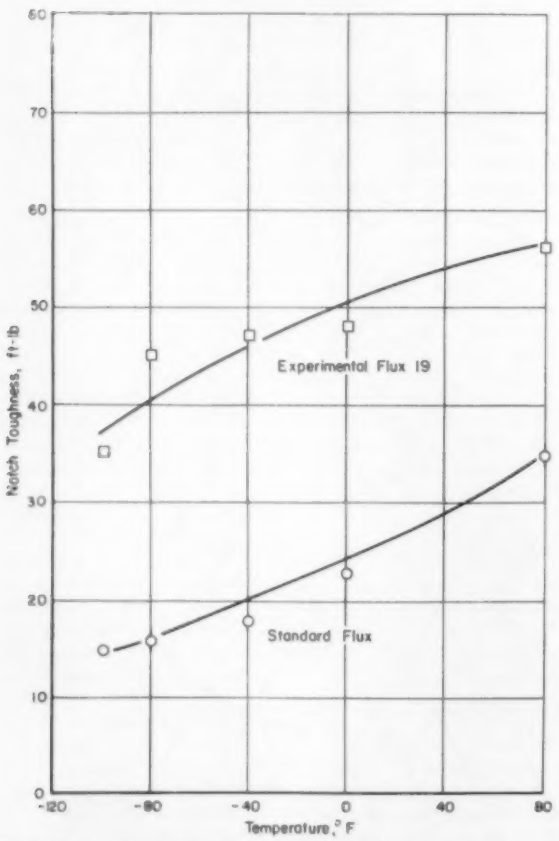

Fig. 4—Comparison of notch toughness of submerged-arc welds made with experimental flux 19 and the standard commercial flux using A-632 filler wire

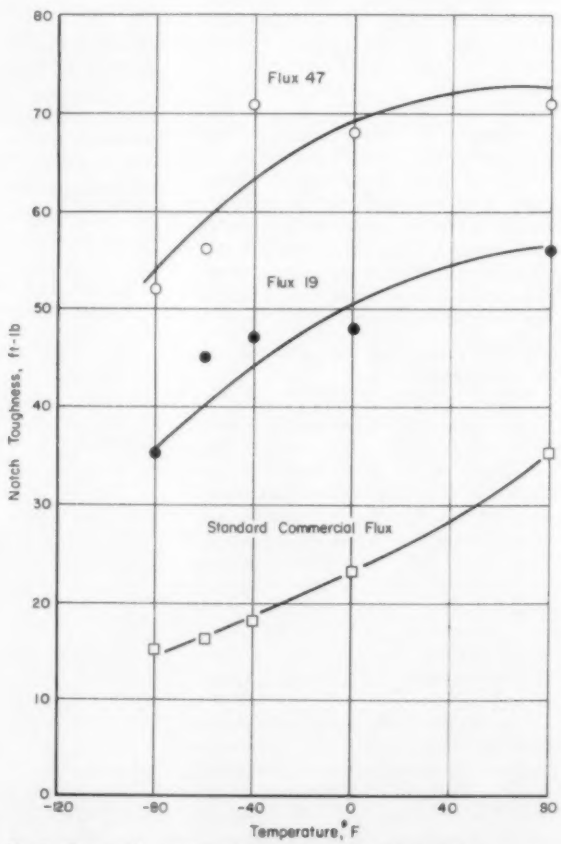

Fig. 5—Comparison of notch toughness of submerged-arc welds made with a commercial flux and experimental fluxes

Table 4—Experimental Fused-flux Compositions in Which the MgO, CaO, MnO and Al_2O_3 Compositions Were Varied

	Intended composition, parts by weight								
Flux	Na_2O	K_2O	MgO	CaO	MnO	Al_2O_3	SiO_2	TiO_2	CaF_2
39	2.2	0.5	0	40	10	0	20	5	20
40	2.2	0.5	0	40	0	10	20	5	20
41	2.2	0.5	0	30	20	0	20	5	20
42	2.2	0.5	0	30	10	10	20	5	20
43	2.2	0.5	0	30	0	20	20	5	20
44	2.2	0.5	0	20	20	10	20	5	20
45	2.2	0.5	0	20	10	20	20	5	20
46	2.2	0.5	0	10	20	20	20	5	20
47	2.2	0.5	10	40	0	0	20	5	20
48	2.2	0.5	10	30	10	0	20	5	20
49	2.2	0.5	10	30	0	10	20	5	20
50	2.2	0.5	10	20	20	0	20	5	20
51	2.2	0.5	10	20	10	10	20	5	20
52	2.2	0.5	10	20	0	20	20	5	20
53	2.2	0.5	10	10	20	10	20	5	20
54	2.2	0.5	10	10	10	20	20	5	20
55	2.2	0.5	10	0	20	20	20	5	20
56	2.2	0.5	20	30	0	0	20	5	20
57	2.2	0.5	20	20	10	0	20	5	20
58	2.2	0.5	20	20	0	10	20	5	20
59	2.2	0.5	20	10	20	0	20	5	20
60	2.2	0.5	20	10	10	10	20	5	20
61	2.2	0.5	20	10	0	20	20	5	20
62	2.2	0.5	20	0	20	10	20	5	20
63	2.2	0.5	20	0	10	20	20	5	20

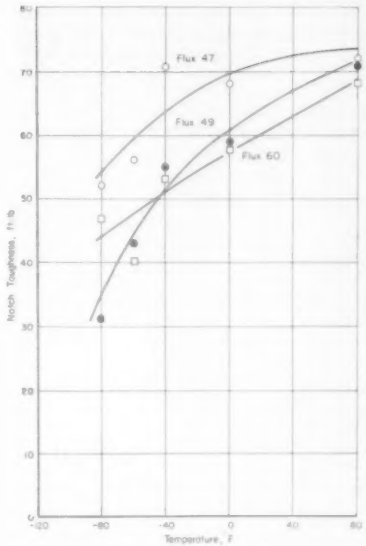

Fig. 6—Notch toughness of submerged-arc welds made with three experimental fluxes

It was believed that changes other than reduced oxygen content and reduced inclusion content also caused improved notch thoughness. Reasoning was the oxygen content and number of inclusions in welds made by the inert-gas-shielded process are less than those made with Flux 47, but the notch-toughness properties at subzero temperatures of the welds made with the new flux are higher than those made by the inert-gas-shielded process (Fig. 8). The causes for these differences in weld-metal notch toughness are not exactly known. However, one of the causes is believed to be a difference in microstructure. In submerged-arc welding, reactions occur between the flux and weld metal. These reactions along with the difference in cooling rate of weld metals made with the two processes could easily affect the weld-metal microstructures. In addition, differences in weld-metal microstructure have been observed in using different fluxes. So far, however, these differences in microstructure have not been observed in comparing weld metals made with the two processes (inert-gas-shielded and submerged arc). Additional metallographic studies are being made to see if significant differences exist.

In addition to the fluxes that were fused with high-purity (reagent grade) additives in fire-clay crucibles, fluxes also were fused with commercial additives in fire-clay and graphite crucibles. These fluxes were made to simulate commercial

Table 5—Compositions of Experimental Filler Wires

	Composition, %									
Wire[a]	C	Mn	Ni	Si	MO	P	S	Total Al	Soluble Al	Ti
1A	0.11	1.42	2.06	0.31	0.53	0.012	0.012	0.17	0.14	...
2A	0.11	1.43	2.05	0.32	0.52	...	...	0.23	0.19	...
3A	0.11	1.47	2.05	0.32	0.52	...	...	0.39	0.32	...
4T	0.12	1.49	2.06	0.33	0.49	...	...	0.10	...	0.08
5T	...	...	...	...	...	...	...	0.08	...	0.15
6T	0.11	1.47	2.02	0.32	0.49	0.014	0.012	0.06	...	0.30
13N	0.11	1.18	2.02	...	...	...	...	...	...	...
14N	0.09	1.12	2.02	0.29	0.50	0.011	0.010	0.085	...	...

[a] The wires were taken from split heats. Heat 1—1A, 2A and 3A; Heat 2—4T, 5T and 6T; Heat 3—13N and 14N.

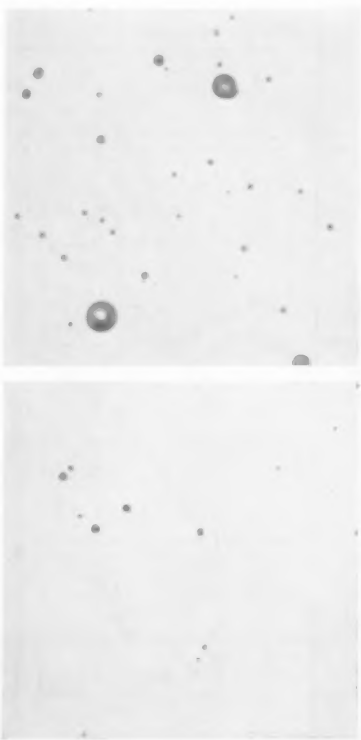

Fig. 7—Comparison of cleanliness of submerged-arc welds made with the standard commercial flux and Experimental Flux 47

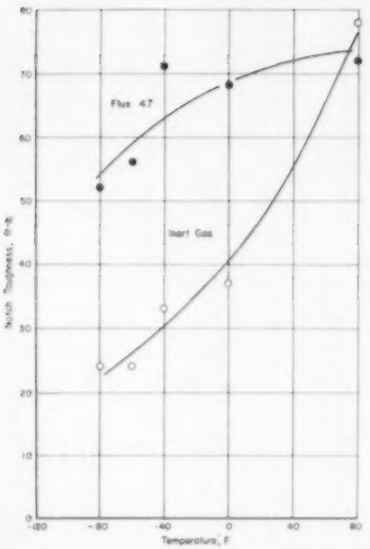

Fig. 8—Comparison of notch toughness of submerged-arc weld metals made with an experimental flux and inert-gas-shielded-arc weld metals

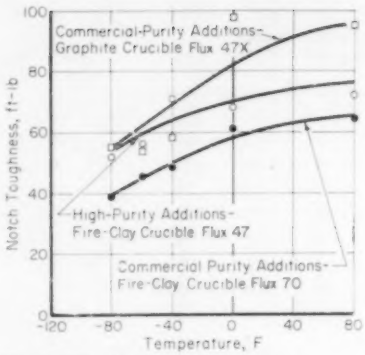

Fig. 9—Effects of flux making practice on weld metal notch toughness.

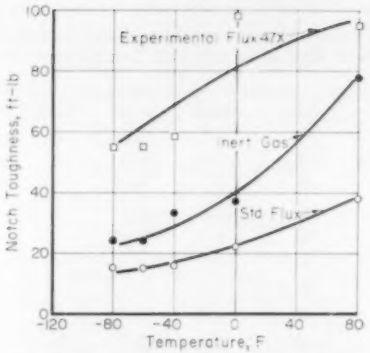

Fig. 10—Comparison of impact properties of weld metals made with standard submerged-arc flux, inert-gas-shielded arc welding, and with experimental submerged-arc flux

practices. The difference between the high-purity and commercial additions were: fused MgO for MgO, CaO for $CaCO_3$, rutile for titania and Wollastonite ($CaO\text{-}SiO_2$) for CaO and SiO_2.

The effects of flux-making practice on weld-metal notch toughness are shown in Fig. 9. The notch toughness of weld metals made with fluxes fused in fire-clay crucibles using commercial additives (Flux 70) was lower than that of weld metals made with high-purity additives. However, the notch toughness of weld metals made with the flux that was prepared from commercial additives and fused in graphite crucibles (Flux 47X) was

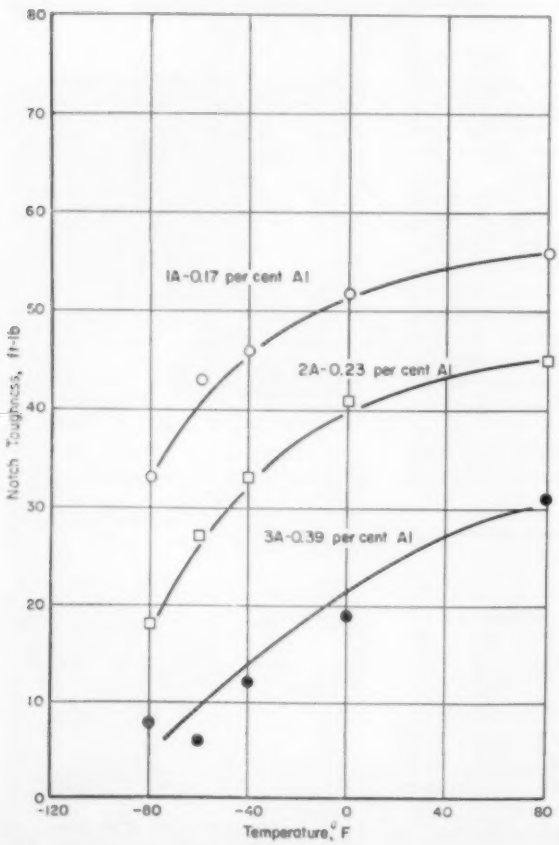

Fig. 11—Effect of aluminum on the notch toughness of submerged-arc welds in HY-80 steel

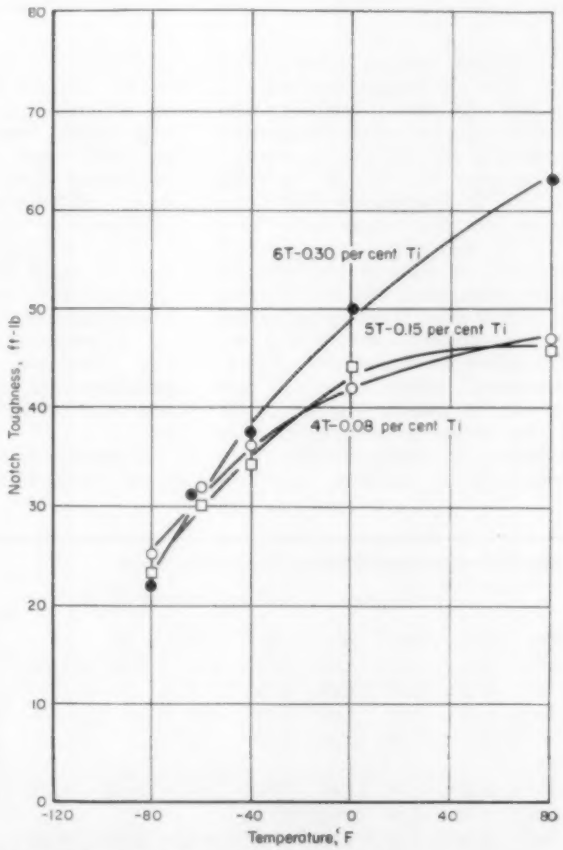

Fig. 12—Effect of titanium on the notch toughness of submerged-arc welds in HY-80 steel

higher than that of welds made with the high-purity additions in fire-clay crucibles. These differences are due primarily to impurities in the additives and reactions between the flux and the fire-clay crucibles. Commercial fluxes are fused in graphite crucibles. Therefore, the experimental flux should be suitable for commercial production.

Figure 10 shows a comparison of the notch toughness of weld metals deposited with the best experimental flux (47X), the inert-gas-shielded process and the standard flux. The notch toughness of welds made with the experimental flux was considerably higher than the notch toughness of the other welds. Although these laboratory results may be better than would be expected in welding under adverse conditions, this information does show the extent that the notch-toughness properties of submerged-arc welds can be improved by varying the flux.

Filler-wire Developments

In the flux studies, the weld-metal notch toughness increased with decreased oxygen contents. It is believed that the oxygen content in the weld metal could be further lowered by using special deoxidation practices in preparing the filler wires. This was done by increasing the amount of deoxidizers normally used in the wire.

Six experimental wires were prepared to study deoxidation practice. The heats prepared for these wires were deoxidized with: (1) 4, 6 and 10 lb of aluminum per ton, and (2) 2 lb of aluminum per ton plus 2, 4 and 8 lb of titanium per ton. The compositions of these filler wires were selected on the basis of information obtained in a previous study[1] and are shown in Table 5.

The filler wires were used to weld 1/2- and 1-in. thick HY-80 steel plate. The welds were made with Flux 70 (same composition as Flux 47 except that commercial additives were used in Flux 70).

The tensile properties of welds made with these wires are shown in Table 6. All of the yield strengths of the weld metals were above 100,000 psi, and the tensile properties were not affected by deoxidation practice.

The wires deoxidized with different amounts of aluminum contained: 0.17, 0.23 and 0.39% total aluminum. The notch toughness of weld metals made with these filler wires are shown in Fig. 11. Weld-metal impact properties were affected by deoxidation of the filler wires. Increased aluminum greatly lowered weld-metal notch-toughness properties.

The filler wires deoxidized with different amounts of titanium contained 0.08, 0.015 and 0.30% titanium. The notch toughness of welds made with these wires is shown in Fig. 12. The notch toughness of weld metals made with filler wires containing 0.08 and 0.15% titanium were about the same. The notch toughness of weld metals made with the filler wire containing 0.30% titanium was the highest of the welds deoxidized with titanium. At testing temperatures above −40° F, the notch toughness of welds made with the 0.30% titanium wire ranged from 5 to 15 ft-lb higher than the notch toughness of welds made with the other two titanium deoxidized wires. However, at testing temperatures of −40° F and below, the weld-metal notch toughness was similar for all three wires.

In comparing Figs. 11 and 12, it can be seen that the welds made with Wire 1A (lowest aluminum content) had the highest notch toughness. So, it was believed that additional studies should be made on filler wires containing less aluminum than Wire 1A. Two additional filler wires were prepared: 13N and 14N. The compositions of the wires are shown in Table 5. Wire 13N did not contain aluminum additions and Wire 14N contained 0.085% aluminum (deoxidized with 2 lb of aluminum per ton). In addition, the wires contained 0.30% less manganese than the first six wires. The notch toughness of welds made with Wires 13N and 14N is shown in Fig. 13; notch toughness data of welds made with Wires 1A, 2A and 3A are included for comparison. Other than aluminum and manganese contents, the composition of all of these wires was comparable. The difference in manganese content (0.30%) of these wires is not believed great enough to affect the weld impact properties so that the changes observed were attributed to aluminum contents. The data in Fig. 13 show that room-temperature, weld-metal notch toughness increased with decreased aluminum contents. Below room temperature, however, the notch toughness of welds made with filler wires without aluminum was lower than that of welds made with wire containing 0.085 and 0.17% aluminum. So, it appears that the filler wires should be deoxidized with aluminum in quantities not more than 2 lb per ton. This finding may

Table 6—Tensile Properties of Submerged-arc Welds Deposited in HY-80 Steel with Five Experimental Wires

Wire	Yield strength (0.2% offset), psi	Ultimate strength, psi	Elongation in 2 in., %	Reduction in area, %
1A	105,000	115,300	20.5	57.0
2A	108,000	117,000	18.6	44.3
4T	106,500	115,300	20.5	50.0
5T	106,500	117,000	21.8	59.1
6T	105,000	118,000	22.0	57.5

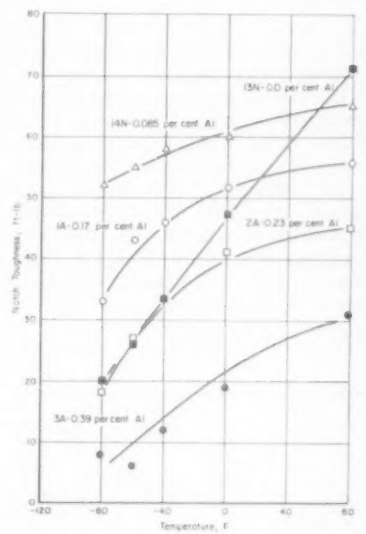

Fig. 13—Effects of aluminum content in the filler wire on the notch toughness of submerged-arc weld metals in HY-80 steel

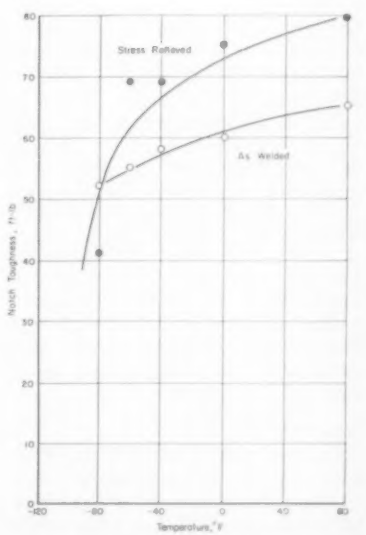

Fig. 14—Notch toughness of submerged-arc welds in 1/2-in.-thick HY-80 steel made with Experimental Wire 14N and Experimental Flux 70

Table 7—Composition of Experimental Filler Wire and Weld Metal

Filler Wire	Chemical Composition, % C	Mn	Si	Ni
14N wire	0.09	1.12	0.29	2.02
14N weld metal	0.10	0.62	0.42	2.13

Filler Wire	Chemical Composition, % P	S	Mo	Al
14N wire	0.011	0.010	0.50	0.085
14N weld metal	0.015	0.010	0.50	0.027

not be the same for the other fluxes studied in the program.

Because of the good impact properties obtained in using Filler Wire 14N, further studies were made. Submerged-arc welds were made with Wire 14N and Experimental Flux 70. The composition of weld metal made with this wire and flux is shown in Table 7. The tensile properties of welds that were made with Wire 14N and Flux 70 are:

Condition of weld	Yield strength (0.2% offset), psi	Tensile strength, psi	Elongation in 2 in., %	Reduction in area, %
As-welded	96,500	109,300	22.7	53.0
Stress relieved	96,500	107,300	23.7	59.1

The yield strengths of the welds made with this wire are well above the minimum of 80,000 psi required.

The notch-toughness properties of welds made with Wire 14N in the as-welded and stress-relieved conditions are shown in Fig. 14. The impact properties of the welds are excellent and are over 40 ft-lb at −80° F in both the as-welded and stress-relieved conditions. On the basis of the weld-metal impact tensile properties, Wire 14N and Flux 70 were selected to be used for welding drop-weight test specimens.

Drop Weight

On the basis of the flux and filler-wire studies, Experimental Flux 70 and Experimental Filler Wire 14N were selected for drop-weight tests. Drop-weight specimens were submerged-arc welded in 1-in. thick HY-80 steel plate using $^5/_{32}$-in. diam wire. Welding procedures

Table 8—Drop-weight Results of Submerged-arc Welds in 1-in.-thick HY-80 Steel Made with an Experimental Flux and Filler Wire

Drop-weight-test results at indicated temperature, °F −100	−120	−140	−150	−160
No break	No break	No break	Break	Break

and joint design are shown in Appendix A. The welds were made under fully restrained conditions. In several of the welds, surface cracks were found in the second weld pass. The cracks ranged in length from 2 to 6 in. long and were about $^1/_{16}$ in. deep. These areas were ground out and the welds completed. All of the welded plates were radiographed after welding. Defects or cracks were not detected in any of the welds.

Standard drop-weight tests were made using the procedures set up by the Naval Research Laboratory. The results of the drop-weight tests are shown in Table 8. The nil-ductility temperature of the weld was found to be −150° F. This result is considered excellent and compares very well with the HY-80 steel plate.

Conclusions

A new submerged-arc welding flux and filler wire were developed for welding HY-80 steel. The notch toughness of welds made with this flux and filler wire were over 40 ft-lb at −80° F, and the yield strengths were over 90,000 psi in both the as-welded and stress-relieved conditions. In addition, the nil-ductility temperatures of weld metals made with the new flux and filler wire were −150° F. Welds with these properties easily meet the requirements for submarine hull construction.

In the flux program, improved notch-toughness properties were accompanied by reductions in weld-metal oxygen and inclusion content. However, low-oxygen and inclusion contents must not be the only factors involved, because submerged-arc welds made with the best flux had higher weld-metal oxygen and inclusion contents than inert-gas-shielded welds. On the other hand, several submerged-arc welds had better impact properties than the inert-gas-shielded welds. The good impact properties obtained with the new fluxes are believed due to changes in weld microstructure.

In developing the filler wire, deoxidation practice played an important role in obtaining weld metals with good notch toughness. Optimum weld impact properties were obtained by deoxidizing with 2 lb per ton aluminum. Deoxidizing with higher amounts of aluminum or without aluminum lowered weld-metal impact properties. The use of titanium as a deoxidizer in the filler wires did not improve weld-metal impact properties.

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APPENDIX A

Experimental Procedures

The experimental fluxes and filler wires studied in this program were prepared in the laboratory. These fluxes and filler wires were then used to deposit submerged-arc welds. The welds were evaluated to study the fluxes and filler wires.

Flux Preparation

The experimental fluxes were prepared in this program using frit-making procedures. Small batches (about 5 lb) were melted in "O" size fire-clay crucibles in a gas-fired pot furnace. In preparing most of the batches, high-purity additives were used. Before melting, the additives were weighed and mixed thoroughly. The batches were melted at temperatures ranging from 2250 to 2700° F with melting times ranging from 30 to 120 min. The melting temperature and time varied with the flux composition and were adjusted for each batch to obtain a molten homogeneous-appearing melt. After melting, the molten fluxes were fritted by

Table A-1—Welding Conditions Used to Make Submerged-arc Welds

	Heat input, 45,000 joules per in.		Heat input, 55,000 joules per in.
	3/32-in. diam wire	5/32-in. diam wire	5/32-in. diam wire
Arc voltage	30	30	30
Amperage	440	550	750
Travel speed, ipm	17.6	22	24.5
Preheat and interpass temperature, °F	250	250	250

quenching in water. The fluxes were dried after fritting by heating them at 500° F for about 24 hr and then were ground to −14 mesh. A few fluxes also were made in graphite crucibles. Induction heating was used to melt these latter fluxes.

In addition to the fused fluxes, some fluxes were mechanically mixed. These fluxes were prepared by making additives to a standard commercial flux and thoroughly mixing them together for welding.

Filler-wire Preparation

The experimental filler wires were prepared in this program using procedures described previously. Briefly, heats were melted under an argon atmosphere in a MgO-lined induction furnace. The normal pouring temperature for all heats was 2980° F. The size of the heats varied from 110 to 310 lb. The 110-lb heats were divided into three 35-lb splits, and the 310-lb heats were divided into three 100-lb splits. Big-end-up ingots were cast from each heat. The ingots were then forged, rolled and drawn to either 3/32- or 5/32-in. diam wire for welding.

Welding and Testing Procedures

The fluxes that were studied in this program were evaluated on the basis of weld-metal notch-toughness properties. All of the welds were made in 1/2-in. thick HY-80 steel plate using 3/32-in. diam filler wire and heat inputs of 45,000 joules per in. of weld bead. The specific welding conditions are shown in Table A-1. A single-vee butt-joint design was used with a 60-deg included angle without a root opening (Fig. A-1). All of the welds were evaluated in the as-welded condition using standard vee-notch Charpy bars.

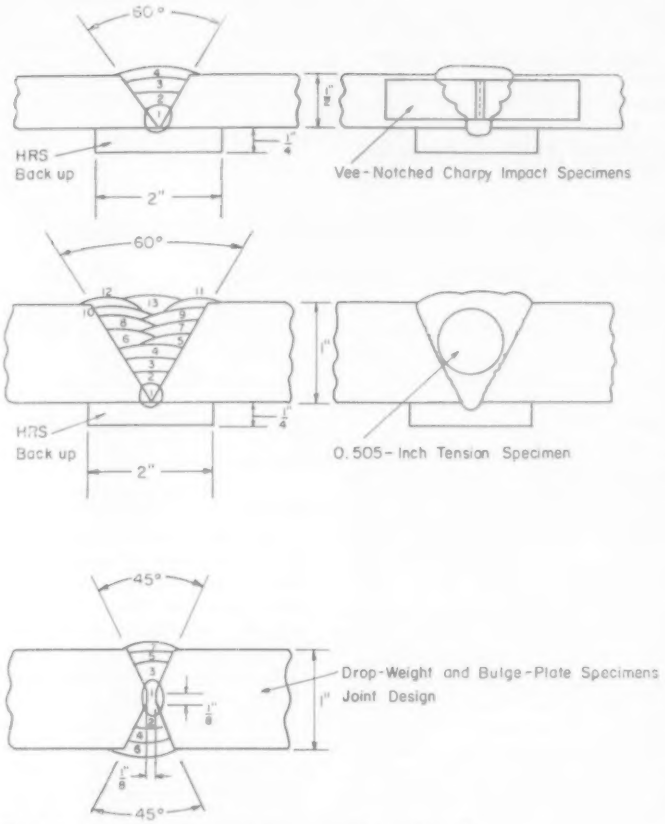

Fig. A-1—Joint design, pass sequence and location of impact and tension specimens in multipass weld

In developing a filler wire, welds were made in both 1/2- and 1-in. thick HY-80 steel plate. The welds were made using 3/32-in. diameter wire and the joint designs and welding conditions used in the flux studies (Table A-1 and Fig. A-1). The welds in 1/2-in. thick plate were machined for standard vee-notch Charpy bars and the welds in 1-in. thick plate were machined for standard all-weld-metal 0.505-in. tensile bars. All of the welds were tested in the as-welded condition, and welds made with filler wires that appeared promising were tested in the stress-relieved condition. The stress-relieving operation consisted of slowly heating the weld joints to 1150° F, holding at 1150° F for 1 hr, and furnace cooling (200° F/hr) to 500° F.

An experimental flux and filler wire selected from this program were used to submerged-arc weld drop-weight specimens. These welds were made in 1-in. thick HY-80 plate using a double-vee joint with a 45-deg included angle and a 1/8-in. land and root opening (Fig. A-1). The welds were deposited with 5/32-in. diam wire. The drop-weight specimens were made using heat inputs of 45,000 joules per in. The drop-weight specimens were tested at Battelle using the procedures developed by the Naval Research Laboratory.[2]

Exothermic Brazing

Copper and silver base exo-reactant compositions are developed for brazing honeycomb panels

BY ROGER A. LONG

Introduction

The use of exothermic reactions for industrial brazing applications has been limited, because little information has been available concerning just what are exothermic brazing materials and concerning the economics of their use.

In order to understand exothermic reactions more fully, one may examine Table 1. In this table are shown some typical metal-metal oxide reduction reactions, their products and the heat evolved. As shown in the last column of Table 1, the calculated quantity of heat released by the reaction is dependent on the choice of the reacting materials and the weight of the reacting mixture.

In order to further understand the basis for the exothermic brazing development, one should examine Tables 2 and 3. The first column in Table 2 lists the more common oxides, while the next three columns show the "heat of formation" for these oxides, with the third column indicating heat of formation per gram of oxide formed. Table 3 shows a sample calculation for estimating the heat evolved by a typical exo-reactant system at 25° C. This value, of course, changes slightly as the temperature increases and considerable calculation is required to determine exactly the theoretical heat evolved at, say, the ignition temperature of the mixture.

The use of these mixtures to supply heat involves a knowledge of some specific exothermic parameters: ignition temperature, reaction duration and net available energy (useful heat). Certain considerations concerning each of these parameters follow below.

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Exothermic Parameters Brazing

Ignition Temperature

All the mixtures of interest in exothermic brazing that produce heat are capable of propagating from the point of ignition throughout the rest of the reaction mass at some specific rate. Local ignition of the exotherm mixture is accomplished by a variety of methods. The easiest and simplest is to ignite them with a flame, hot wire or hot spark and allow the reaction to propagate like a fuse. Over-all, simultaneous ignition of the entire exothermic mixture can be obtained only by heating the mixture evenly to the ambient ignition temperature. Ignition temperature thus signifies the temperature at which the system initiates spontaneous propagative reaction. The requirements for propagative reaction are based on the rate theory. The essential requirement is that the net heat gained from the reaction, plus any heat supplied externally, must be greater than the heat energy absorbed when activating additional adjacent reacting molecules.

Therefore, the rate of the ignition reaction is dependent primarily upon the effective concentration of the reacting materials and in solid-solid reactions; this is determined by the amount of particle surface areas in contact or in near contact.

Reaction Duration

For a given quantity of reactants, the duration will be limited by the rate at which the reactants are

Table 1—Metal-Metal Oxide Reactions

Formula no.	Exo-reactants	Products	Theoretical heat evolved,[a] K cal/g
(a)	$2Fe + Bi_2O_3$	$Fe_2O_3 + Bi$	0.11
(b)	$2Fe + 3CuO$	$Fe_2O_3 + 3Cu$	0.24
(c)	$Mn + CuO$	$MnO + Cu$	0.40
(d)	$10B + 3V_2O_5$	$5B_2O_3 + 6V$	0.73
(e)	$2B + 3CuO$	$B_2O_3 + 3Cu$	0.73
(f)	$2Al + MoO_3$	$Al_2O_3 + Mo$	1.14
(g)	$2Mg + MnO_2$	$2MgO + Mn$	1.20
(h)	$4Li + MnO_2$	$2Li_2O + Mn$	1.40

[a] K cal per gram of reactant mixture based on —H 298° K.

Table 2—"Heat of Formation" Data for Oxides, (Kcal)

Oxides	—H 298° K per mole	—H 298° K per oxygen atom	—H 298° K per gram oxides
Ag_2O	7.3	7.3	0.03
Al_2O_3	400	143.8	3.93
B_2O_3	302	101	4.34
Bi_2O_3	138	46	0.3
Cr_2O_3	270	90	1.78
Fe_2O_3	197	65.5	1.21
Li_2O	143	142.6	4.75
MgO	144	143.8	3.56
MnO_2	125	62.3	1.42
MoO_3	180	60.1	1.25
SiO_2	211	105.2	2.33
V_2O_5	373	74.5	2.06
ZrO_2	262	130.8	2.13

Table 3—Calculation of Heat Evolved in an Exothermic Reaction at 298° K

(1) $2Mg + MnO_2 = 2MgO + Mn$
From the heat of formation at 298° K of the oxides, the heat evolved in eq 1 can be calculated.
(2) $2Mg + O_2 = 2MgO + 287.6$ Kcal
(3) $Mn + O_2 = MnO_2 + 124.5$ Kcal
Subtracting (3) from (2) gives a value of H at 298° K of 163.1 Kcal. Also since the gram molecular weight of the reactants is equal 135.6 g then 1.2 Kcal of heat will be released for each gram of exo-reactant mixture.

Table 4—Average Ignition Temperatures, ° F, and Approximate Duration Times of Stoichiometric Mixtures

Oxide	Metal: Avg. particle size, Micron	Mg +40 Mesh	Mg −100 Mesh	Al 5	Ti −325	Si 5	B 1	ZrH_2 4	Zn 15	Fe 3
CuO	4	(12)[a] 1045	1090	(1)[a] 1640	(2)[a] 970	1745	(5)[a] 930	(6)[a] 770	(6)[a] 1095	(13)[a] 860
CuO	1	(2)[a] 1020	(1)[a] 1030	...	...	...	(11)[a] 930	...	...	(5)[a] 700
Bi_2O_3	1	940	...	1260	...	...	...	...	1110	510
MoO_3	4	1220	...	1220	...	...	...	...	...	...
MnO_2	3	(25)[a] 1020	(32)[a] 1140	1650	...	(1)[a] 1880	(5)[a] 1080	...	(25)[a] 1040	[b]
Fe_2O_3	0.4	(18)[a] 1140	...	(8)[a] 1700	(20)[a] 1480	1650	(8)[a] 1070	(2)[a] 880	(8)[a] 1390	[b]
SnO_2	0.6	...	1070	(8)[a] 1702	...	...	1090	...	...	[b]
V_2O_5	1	1550	1520	(4)[a] 890	(5)[a] 1010	...	(19)[a] 860	(9)[a] 790	...	[b]
Mn_3O_4	3	...	1100	(7)[a] 1750	...	...	(13)[a] 1350	...	...	[b]

[a] Reaction duration time in seconds (shown in parentheses).
[b] Instantaneous reaction.

consumed and products formed. Thus, reaction durations can be varied by:

1. The addition of inert materials which absorb heat.
2. Adding a third substance that reacts at a different rate.
3. Using nonstoichiometric proportions.
4. Varying powder particle sizes.

Net Available Energy

This defines the "useful heat" of any particular reaction and can be theoretically calculated by use of the previously mentioned procedures. Experimentally, this heat can be determined by measuring the area beneath the time-temperature curve for any particular reaction. It is more advisable, from an applied research approach, to establish a standard procedure using one standard reaction mixture and compare all others to it. The heat losses in each case due to this technique can be considered near equal and, therefore, the results can be compared.

Experimental Evaluations

The theory of exothermic reactions and some parameters has been discussed briefly. At this point it seems appropriate to consider some of the experimental work that has been performed.

Considerable effort has been spent on understanding the reactions and factors such as safety problems, methods of preparation, the ignition temperatures, the reaction duration and effects of powder particle size and effects of additions. Not all of this work can be related here, but it is possible to examine the factors more pertinent to the bonding problem.

Table 4 gives the ignition temperatures obtained with the various metal-metal oxide mixtures. The particle sizes are listed because of their basic influence. This table, by its construction, shows the greatest "heat release" reactions in the upper left hand corner, with the amount of "heat release" decreasing as one proceeds downward and/or to the right.

Ignition temperature appears to be a more or less intrinsic value. However, a number of interesting points are quickly observed. All aluminum containing mixtures have high ignition temperatures, except when aluminum is mixed with vanadium pentoxide. Magnesium mixtures are just the opposite: low ignition temperatures except when used with vanadium pentoxide. No definite explanation can be made although many theories can be advanced. The lowest ignition temperature in the overall investigation was 450° F for the combination silver oxide and very fine iron powder. The highest, 1880° F, was for the reaction silicon and manganese dioxide.

Reaction duration was seemingly not related to the position of the reactants in Table 4. In general, however, heats of reaction of less intensity seem to give longer reaction durations, provided particle sizes are similar.

The influence of reactant mass on ignition is of most importance, particularly for those combinations that are less exothermic, i.e., those located downward and to the right in Table 4. In many instances, even with some of the more exothermic reactants, one (1) gram disk pellets would not ignite when sandwiched between two 50 mil stainless steel sheets but would ignite between 25 mil sheets. A thin adjacent metal does not prevent propagation; a thicker metal does. A metal of higher thermal conductivity prevents propagation, while one of lower conductivity allows propagation. These are mainly factors only when working with a small mass of mixture or working with mixtures having low heat releases.

To determine generally the effect of adding inert materials, additions of stable oxides were made. Experimentally, the composite system Al-(V_2O_5 and Fe_2O_3) was used with increasing percent additions of about 44–60 micron alumina (aluminum oxide). Table 5 shows that reaction duration can be almost tripled with a 20 weight percent alumina addition without affecting the ignition temperature; greater weight additions had no further effect on duration but eventually stopped the ignition. Other data showed similarly that silica additions could be made without detriment to the reaction characteristics.

It was also desirable to check the ignition characteristics of various "exo-reactant" mixtures in argon atmosphere and vacuum. Results showed an increase in ignition temperature of up to 100° F over that of the same mixtures ignited in air. Other characteristics were the same. No attempt was made to determine the reason.

These preliminary investigations had to be conducted because little or no literature data was available on the reaction characteristics of

Table 5—Effects of Alumina as a Reaction Duration Extender

Composition, % Al + Oxides	Alumina	Ignition temperature, ° F	Maximum indicated temperature, ° F	Duration, sec
100	0	1400	1820	12
95	5	1400	1820	20
80	20	1400	1820	30
67	33	1690	1920	40
50	50	1740	1850	35
44	56	[a]	...	..
40	60	[a]	...	..

[a] No reaction.

Table 6—Silver Brazed Tensile Lap Shear Specimens

Specification No.	Method	Area brazed, %	Test temperature, °F	Shear strength, psi
7	Exo	100	R.T.	23,600
13	Exo	100	R.T.	26,900
14	Exo	80	600	12,300
8	Exo	100	600	16,600
10	Std.	100	R.T.	23,700
12	Std.	100	R.T.	21,400
9	Std.	100	600	18,600
11	Std.	90	600	15,100

various exothermic combinations. Utilizing the information obtained, a braze bonding program was established with hopes that it would lead to the development of a silver base brazing filler metal, a copper base filler metal and a nickel base filler metal as reported below.

Braze Bonding

Application of Reaction Heat to Preplaced Alloys

Two different processing methods can be envisioned using controllable exothermic reactions. One method—"Exo-adhesive Bonding"—is described below under separate heading. The simpler method is a process whereby the reaction heat is utilized to bring an adjoining or a nearby metal interface to a temperature where an already preplaced braze alloy will melt and wet the metal interface surfaces. In this case, the braze alloy can be any commercially available brazing material having suitable flow temperatures. The limitations are due to the thickness of the metal that one must heat through and the effects of this heat, or any previous heat treatment, on the metal properties.

Utilizing exothermic data, the boron-vanadium pentoxide system was selected as a heat source for making lap shear specimens of 50 mil thick 17-7 PH stainless steel. The brazing alloy selected was American Platinum alloy AE-100 (92.5% Ag, 7.2% Cu, 0.25% Li) which has a flow temperature of 1635° F. The following procedure was used:

1. The stainless steel surface and brazing alloy foil was degreased, scrubbed with Ajax cleanser, rinsed and dried.
2. The overlap shear panels, with the foil brazing alloy in the lap joint, were edge tack welded along the overlap to maintain alignment.
3. The "exo-reactant" mixture, (approximately 0.6 g. per in.^{2}) suspended in alcohol, was painted opposite the joint lap on each of the back surfaces of the stainless panels and then wrapped in a Fiberfrax blanket, then heat lamp dried.
4. The assembly was inserted into an argon atmosphere resistance wound tube furnace and the temperature was increased approximately 900–950° F where ignition occurred.
5. The external reaction products were washed off in hot water, and the bonded specimen was heat treated to condition TH 1050 recommended for 17-7 PH materials.

Table 6 compares specimens brazed by both exothermic and by standard heating methods. Shear strengths are equivalent. It is of interest to note that one exo-brazed specimen gave the highest shear strength obtained—about 15% higher than that obtained by standard furnace procedure. This was not unexpected, as better wetting and flow of a noneutectic silver braze alloy should be obtained under fast heating conditions.

These tests showed that it was possible, with a small quantity of "exoreactant" mixture, to produce sufficient heat to perform brazing operations. Since these initial experiments, experimental stainless honeycomb panels up to two square feet in area have been produced by this external exotherm technique. The method has also been used to locally braze inserts into panels, to attach small parts to larger structures, and is being considered as a field repair mechanism for aircraft structural honeycomb panels. This type of heat source has also been used as a preheating method prior to sheet metal forming and/or explosive forming.

Exothermic mixtures produced in tape form are presently available with various heat inputs per square inch of area.

Exo-adhesive Bonding

An alternate method of exothermic joining can be designated "Exo-adhesive Bonding." This is a process where the "exo-reactant" materials are not only used as a heat source, but the metallic products of the reaction are used as the bonding adhesive. This approach requires considerably more exacting formulations of the "exo-reactant" mixtures so that the products of the reaction will form an acceptable metal alloy, which when molten will wet and bond the adjoining metal surfaces.

The development program was initially divided into two parts: "Oxide-Metal" systems and "Metal-Glass Forming" systems. Table 7 lists some of the combinations investigated. The first three are examples of the "Oxide-Metal" system, the next two of the "Metal-Glass Forming" system, and the last is an example of a combination system.

Investigation indicated that a combination system was necessary to assure an all metallic braze bond. The "Oxide-Metal" systems would not allow for separation of the oxide by-products from the metallic by-products. The "Metal-Glass Forming" systems produced bonds with an excess glass phase; these bonds were brittle and of low strength. Combination systems in which the mixture components were not optimumly balanced showed metallic bonding with included glass;

Table 7—Exo-adhesive Reactant Mixtures and Their Products

System formula No.	Exo-reactants	Adhesive products	Theoretical heat evolved,* Kcal/g
B-1	5% Ti + 5.6% Mg + 85% Cu_2O + 9.4% SnO_2	26.3% CuSn + 72.7% oxide	0.6
I	12.1% Al + 78.1% Cu_2O + 9.8% SnO_2	80% CuSn + 20% Al_2O_3	0.64
E	25% Mg + 52.3% NiO + 22.8% MnO_2	59% MiMn + 41% MgO	0.96
K	7.1% Borax + 16.4% SiO_2 + 6.4% B + 70.1% CuO	55.3% Cu + 44.7% glass	0.73
P	7.4% Borax + 17.6% SiO_2 + 6.6% B + 68.4% NiO	54% Ni + 46% glass	0.51
R	System K + System B-1	...	...

* Based on —H 298° K.

however, joint lap shear strengths were over 2000 psi. It was now possible to see the future development mechanism for eventual program success; in other words, a basic breakthrough has been established.

The reaction rate of the bonding process is so rapid (1 to 5 sec) that compositional balances in the "exo-reactant" mixture are important factors. For example, it is necessary to control the flow characteristics of the glass component produced during the reaction, and it is also necessary to remove this glass from the joint area while it is still fluid. Therefore, the composition of this formed glass is important in that composition affects fluidity. Also, since the fluidity of the glass is a function of temperature, the useful heat produced by the reaction becomes of basic importance. The formed glass composition can be controlled by additions to the original basic mixture of inerts like silica, lithia, alumina and borax. Boron additions can also be made to the original mixture when it is felt that the boric oxide content of the glass should be increased.

The use of pressure, to assist in squeezing out the glass phase, was also found to be of importance. Pressures from 50 to 200 psi have been used; however, too great a pressure causes not only extrusion of the glassy phase but most of the metal phase. The applied pressure must be adjusted for each exothermic mixture.

A most important factor in braze bonding is the wetting of the stainless steel surface by the metallic by-product of the exothermic reaction. Since all bonding was desired to be achieved in an air atmosphere, extensive oxide formation on the stainless steel surface during any heat up period prior to ignition and/or during ignition would prevent metallic wetting. It was therefore necessary to approach this problem as one involving metallic braze bonding. Since the glass component was already present, it was fairly simple to increase the wetting and oxide absorbing efficiency of this glass. This was done by adding up to 6% of various glass soluble halides. Immediately, definite improvements in metallic wetting were noted. A further improvement in wetting was accomplished by adding approximately 2 weight percent of either copper or silver metal powder. This small metal addition was made because it was felt that, if metallic wetting could be initiated during the early portion of the reaction time period, subsequent wetting by the metallic products, when formed during the reaction, would be easier to accomplish. A substantial wetting improvement was noted with these small metal additions, and they became part of all basic "exo-reactant" formulations.

Table 8—Exo-reactant Adhesive Formulations

	Copper producing system	Silver producing system 1	Silver producing system 2
Reactant metals, %	7.2 Mg	9.4 Mg	7.7 Mg
	3.0 B	2.9 B	3.4 B
Reactant oxides, %	34.6 Cu_2O	36.6 Ag_2O	30.2 Ag_2O
	32.3 CuO	32.2 CuO	37.1 CuO
	4.1 SnO_2		
Inert metal, %	2.0 Cu	2.0 Ag	2.3 Ag
Inert oxides, %	3.3 Borax	3.3 Borax	3.7 Borax
	7.5 SiO_2	7.6 SiO_2	8.7 SiO_2
Wetting agent, %	3.3 KHF_2	3.3 KHF_2	3.8 KHF_2
	2.0 Li_2F	2.0 Li_2F	2.3 Li_2F
	0.6 KCl	0.6 KCl	0.7 KCl
	0.1 Pluronic	0.1 Pluronic	0.1 Pluronic
	Reaction products		
Metallic, %	58.1 Cu	36.2 Ag	29.5 Ag
	3.4 Sn	25.4 Cu	28.8 Cu
Nonmetallic (glassy), %	12.1 MgO	11.9 MgO	12.4 MgO
	7.5 SiO_2	7.8 SiO_2	8.4 SiO_2
	1.0 Na_2O	1.0 Na_2O	1.1 Na_2O
	11.9 B_2O_3	11.7 B_2O_3	13.0 B_2O_3
Ignition temperature and heat	890° F—550 Cal/g	1010° F—475 Cal/g	1000° F—517 Cal/g

A brief insight into the procedures for using this type adhesive is of interest: The reactant powder mixture, previously mixed and well blended, is either painted on the bonding surfaces by using an alcohol carrier, or the mixture is die pressed to form a thin wafer. In either case, the mixture is placed between the surfaces to be bonded. The weight of the exo-reactants varies, depending on the thickness of the stainless steels being bonded. An average weight would be about 1 g of reactant per square inch of bonding surface of 25 mil thick stainless steel. The entire assembly, which has been wrapped in Fiberfrax insulation, is heated rapidly (1–3 min) in a preheated furnace to cause ignition. (Ignition can also be accomplished at room temperature.) Pressure is applied during the firing operation. Heat treatment of the steel is performed after the bonding operation. In many cases, when the metal is thin, the solution heat treating can be combined as part of the bonding operation and only the aging treatments are required.

Two "exo-reactant" formulations are listed in the first two columns of Table 8 detailing the finally devel-

Table 9—Tensile Lap Shear Strengths—Age Hardenable Stainless Steels

Type of steel, braze and heat treatment	Test temperature, ° F	Avg. joint shear[a] strength, psi	Avg. base metal tensile strength at failure, psi
17-7 (TH 950)			
(Ag Formulation 1)	80	>9,000	180,500
(TH 1050)	600	>7,300	88,000
(TH 1050)	800	>8,350	96,000
15-7 Mo (TH 1050)	80	>13,750	150,000
(Ag Formulation 1)	600	>11,100	140,000
	800	>10,700	120,000
AM 350 (hardened)	80	>8,600	110,000
(Ag Formulation 1)	600	>8,900	110,000
	800	>7,700	95,000
17-7 (RH 950)[b]	80	>5,900	122,000
(Cu Formulation)	1000	>2,800	61,500

[a] All specimens failed outside lap joint—data avg. 3 test specimens.
[b] Aged only at 950° F after exo-brazing and cold treatment.

oped copper base and silver base "exo-reactant" compositions. Variations in these compositions can be made, but a balance in "useful heat" produced and in "reaction products formed" must be maintained. For example, the formulation in the third column is currently being used for brazing thin (3 mil) stainless metal honeycomb foil to thicker (7 mil) skin foil for honeycomb panel fabrication. This compositional change was found necessary over Silver Producing System 1 (column 2) because the heat produced by 1 was not sufficient, the resulting formed glass had a low fluidity, and portions remained in the joint area. By increasing the heat, this problem was eliminated; however, it was found that too large a heat increase destroyed the thin metal core.

The shear strengths of age-hardenable stainless steel lap joints produced by this brazing technique were not conclusive as to braze strength, as all failures occurred in the parent metal adjacent to the lap shear joint, even though the overlap was decreased to bare minimum. Data are shown in Table 9 for both room temperature and elevated temperatures.

Conclusion

This has been a review of development work covering approximately a year and a half of effort. The latter exo-adhesive technique has recently been adapted to fabricating silver brazed stainless steel honeycomb panels. The process is still being determined, but panels have been made. In addition, development is under way on a nickel base system which would have high temperature usage possibilities.

Acknowledgments

The author wishes to thank his colleagues at Narmco Research and Development—William Bassett and Robert Caughey—who assisted in this development, and Jay Stevens, Project Engineer, Bureau of Naval Weapons, Department of the Navy, for his support and interest in this project.

EUROPEAN WELDING RESEARCH

By Gerard E. Claussen

AUSTRIA

The Austrian welding magazine *Schweisstechnik* for October 1960 summarizes three papers presented at a welding conference in October 1959. The first article provides information for submerged-arc welding sheet steel. For example, a sheet $^1/_8$ in. thick is welded to a $^1/_4$-in. cylinder at 520 amp, 83 ipm with a constant voltage rectifier and $^3/_{32}$ in. electrode. The second: in the welding of nickel, titanium is added, Ti = 6 × C, to combine with carbon to avoid corrosion difficulties and to combine with oxygen to avoid porosity. The third: for submerged-arc surfacing of worn rolls for briquetting machines, a wire containing 0.3 C, 0.2 Si, 0.8 Mn and 2.5 Cr is recommended.

BELGIUM

The following articles appeared in the third quarterly issue of *Revue de la Soudure* for 1960:

• The principles of electroslag welding are explained by a manufacturer of two types of electroslag equipment. One type is a light head for thicknesses up to 4 in. The heavy machine is for sections up to 18 in. thick. The weld metal contained 0.16 C, 1.33 Mn, 0.06 Si, 0.016 S, 0.011 P and had low-Charpy V impact value unless normalized. Russian applications of the process to pressure vessels and rolling mill frames are illustrated.

• A high-class review of literature with hitherto unpublished results is given on the subject of hydrogen in weld metal. Microfissuring is considered to result from the cooperative action of a number of effects: shrinkage stresses, transformation to martensite of small pools of austenite saturated with hydrogen, trapping of hydrogen in porosity, at interfaces between metal and inclusions and at dislocation pile-ups.

The effectiveness of an interpass temperature of 250° F in preventing microfissures is pointed out.

EAST GERMANY

Schweisstechnik for October 1960 contains the following research articles:

• In machine cutting, killed mild steel plates $^1/_8$ to $2^1/_2$ in. thick, with a tip having the customary German annular preheating orifice, it was possible to lower the acetylene consumption 70 to 80% without disadvantage. The allowable preheat time in the tests increased from 2 sec for $^3/_8$-in. plate to 9 sec for $2^1/_2$-in. plate. As the acetylene consumption was lowered, the surface of the cut became smoother.

• The results of stress distribution, torsion and fatigue tests on chassis of tilting trailers for trucks showed that welded connections should be made to the flat side of the channel, not to the legs. Undercut, craters and porosity increased the likelihood of cracking.

• A *Schlieren* study of nozzle designs for CO_2 welding showed that a conical nozzle with 14-deg included angle and circular cross section was best. Exact centering of the tapered contact tube and a straight length of 3 in. for the CO_2 to lose turbulence before entering the arc were important. The inside diameter of the nozzle at exit was 0.59 in. With a nozzle-to-work distance of $^3/_8$ to $^9/_{16}$ in., a wind of $4^1/_2$ mph, about the same as the exit velocity of the CO_2, could be tolerated.

• The literature on the theory of distribution of stress in lap joints with combined end and side fillets is reviewed. Numerical solutions are given for the biaxial stress theory of

(*Continued on page 363-s*)

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Ultrasonic Welding of Heat-Resisting Metals

Only welds in titanium and between stainless steel, iron and columbium appear to have acceptable cross-tension strengths in an investigation which included molybdenum and Inconel

BY N. E. WEARE AND R. E. MONROE

ABSTRACT. Ultrasonic spot welding of various combinations of heat-resisting alloys was studied. Room-temperature tension-shear and cross-tension strengths were obtained for each combination. Generally, the room-temperature strengths of these welds were low, especially cross-tension strengths. Only the welds in titanium and between stainless steel, iron and columbium appeared to have acceptable cross-tension strengths. Metallographic examinations indicated that cracking occurred at the edge of the weld area. In many instances, the cracking was extremely serious and definitely contributed to the low strengths of the joint. This cracking was believed to be caused by high-concentrated cyclic stresses at the edge of the weld, producing fatigue failures. Methods have been proposed to eliminate the cracking. No evidence of melting, diffusion across the interface or the formation of intermetallic compounds was noted in sections examined.

Introduction

In recent years, intensive research programs have furthered the ability to use many materials possessing good high-temperature properties. Although many of the problems involved in working with materials such as molybdenum and columbium have been solved, the joining of dissimilar metal combinations still presents many problems. The ability to produce satisfactory dissimilar metal joints would alleviate many problems and make it possible to utilize refractory metals only where their unique properties are required.

Adaptation of conventional fusion-welding methods to this problem has not been possible because of certain metallurgical properties of the materials involved. The basic failing of the conventional welding methods is that extensive melting or diffusion takes place when these methods are used. This promotes the formation of intermetallic compounds in many combinations. The heating involved also allows contamination of the base materials with impurities from the surrounding atmosphere. Intermetallic compounds generally result in joints with low ductility and shock resistance. Contamination of the base materials also may drastically affect the properties of the weldment.

Ultrasonic welding offers a possible solution to the problem of welding refractory metals and producing weldments between dissimilar metals for high-temperature applications. Even though a portion of the energy required to produce a bond appears at the interface as heat, it is not applied for extended periods of time. The formation of intermetallic compounds and contamination of the weld may be suppressed.

A research program was initiated to determine the suitability of ultrasonic welding for joining the following materials:

1. Titanium to AISI 316 stainless steel
2. Titanium to titanium
3. Molybdenum to molybdenum
4. Molybdenum to AISI 316 stainless steel
5. Columbium to AISI 316 stainless steel
6. Columbium to iron to AISI 316 stainless steel
7. Columbium to Inconel

Factors influencing the formation of welds and the room-temperature properties of these welds were studied.

Experimental Procedures

During the course of this investigation, equipment and instrumentation was developed to study the fundamentals of the process as well as the joining of heat-resisting materials.[1] The following sections discuss the materials, equipment and instrumentation and welding and testing procedures.

Materials

Certain materials were selected, because it would be desirable to produce joints in various combinations of these materials in order to utilize the unique properties of the refractory metals only where they are required. The materials used in this study were commercially pure titanium, molybdenum - 0.5% titanium, columbium AISI 316 stainless steel, Inconel and iron. Information on these materials is given in Table 1.

Equipment and Instrumentation

An ultrasonic welding unit was assembled for the specific purpose of this experimental program. This unit allowed ease of instrumentation not accomplished in commercially available equipment. The unit consisted of a 2.4-kw power oscillator and a 20-kc water-cooled transducer. The transducer was mounted in a horizontal plane so that welding-tip motion was parallel to the surface of the sheet being welded. Welding tips were mounted on the transducer coupling body as shown in the block diagram (Fig. 1).

Clamping pressure was applied to the materials being welded by an air cylinder. Weld time was controlled by an X ray timer. Various weld tip and anvil designs were studied, but these studies are not within the scope of this paper.

The welding unit was instrumented in a manner which allowed measurements of the welding variables, power, weld time and clamp-

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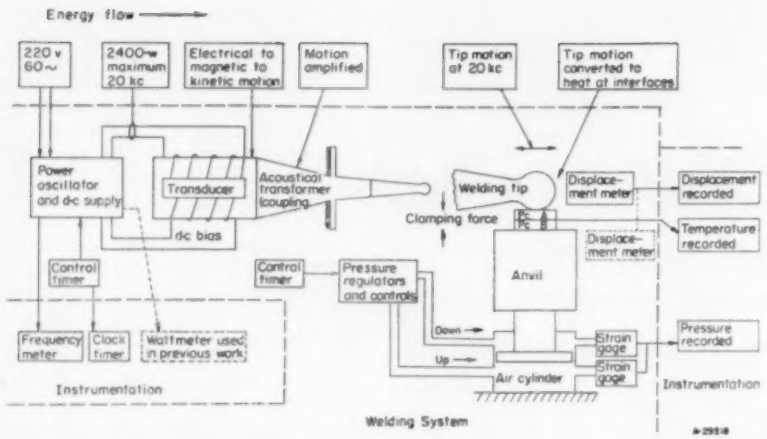


Fig. 1—Block diagram showing ultrasonic welding system, instrumentation and energy flow

Table 1—Data on Materials for Ultrasonic Welding Studies

Material	Alloy designation	Thickness, in.	Condition	Hardness,* DPH
Titanium	MST Grade III (A-70)	0.020	Hot rolled and annealed	188
Molybdenum	Mo – 0.5% Ti (arc cast)	0.015	Rolled approximately 80% reduction and stress relieved	296
Columbium	Commercially pure (powder metallurgy)	0.020	Rolled and annealed	83.6
Stainless steel	AISI Type 316	0.018	Cold rolled, No. 2B finish	135
Inconel	...	0.018	Cold rolled	118
Iron	High purity	0.005	Cold rolled in excess of 90%	165

* All DPH values measured with 5-kg load except iron, 1-kg load.

Table 2—Summary of Cleaning Procedures Used During This Investigation

Material to be welded	Degreasing agent	Etchant	Etchant temperature, °F	Time in etchant
Molybdenum	Trichloroethylene	95 parts H_2SO_4, 4.5 parts HNO_3, 0.5 part HF and 18.8 g/l Cr_2O_3	120–140	30 sec
Columbium	Trichloroethylene	90 parts HNO_3, 10 parts HF	Room temperature	15–30 sec
Titanium	Trichloroethylene	50 parts H_2O, 45 parts HNO_3, 5 parts HF	Room temperature	30 sec
AISI 316 stainless steel	Trichloroethylene	81–86 parts H_2O, 10–15 parts HNO_3, 2 parts HCl, 2 parts HF	120–140	10–20 min
Inconel	Trichloroethylene	100 parts H_2O, 100 parts HNO_3, 15 parts HF	70–100	15–90 min
Iron	Trichloroethylene	8–10% H_2SO_4 solution	Room temperature	15–30 sec

ing force. Previous investigators have measured power as r-f watts delivered to the transducer.[2–6] This method was not considered acceptable in this study, since power delivered to the weld tip is not a linear function of power delivered to the transducer. Also, the efficiency of power delivery to the weld tip was not known. Weld-tip displacement is a function of the power available for welding. For this reason, it was decided that power would be measured as actual weld-tip displacement during the weld cycle. This was accomplished by the use of a capacitance pickup at the tip which detected changes in the air gap between the weld tip and a capacitance plate. Changes in the capacitance unbalanced one side of an inductively coupled dual oscillator circuit[7] resulting in a power transfer through their coupling circuit. A signal from the coupling circuit was metered to give a measure of welding-tip displacement. Weld time was measured by a clock timer and clamping force was determined from readings on a pressure gage on the air cylinder. Weld tips were machined from Monel since it has good fatigue strength and is a good transmitter of ultrasonic energy. Mild steel and drill rod anvil materials were used.

Welding Procedures

Certain procedures were adhered to in producing joints for the study of ultrasonic welding of heat-resisting materials. The procedures used in this program were as follows:

1. The materials were degreased and cleaned just prior to welding.
2. The sample to be welded was placed on the anvil and clamping pressure was applied to clamp the specimen between the tip and anvil.
3. The capacitance-plate-displacement meter was adjusted to the proper air gap.
4. The ultrasonic energy cycle was activated for a preset time.
5. A short period after the completion of this cycle the clamping pressure was released and the weldment was removed.
6. The weld tip and anvil were cleaned by abrading them with fine emery paper.
7. The weldment was then either broken apart to examine the bond, tested in a tension-shear or cross-tension test, or sectioned for metallographic examination.

Table 2 summarizes the cleaning procedures used for the materials studied. Tabs $^1/_2$ by 1 in. by the sheet thickness were used for producing tension-shear and cross-

tension tests. Testing was carried out in a 500-lb tension testing machine.

Experimental Results

This investigation was made to adapt ultrasonic welding to the production of acceptable joints in the selected heat-resisting metals. Originally, the properties of the joints were to be determined at room and elevated temperatures. Limited room-temperature strength data were obtained. However, metallographic examinations indicated the presence of cracks at the edge of the bond in the refractory metal of the above combinations. The elimination of cracking then assumed the primary role in this investigation. This cracking is illustrated by the macrographs shown in Fig. 2.

The nomenclature used to describe the weldments discussed in these sections indicates the position of the materials during welding. For instance, Inconel to columbium indicates that the Inconel was directly beneath the weld tip while the columbium was against the anvil. This nomenclature does not hold for the section headings.

The following sections describe the results of this investigation for each of the heat-resistant weldments.

Titanium to AISI 316 Stainless Steel

The titanium to AISI 316 stainless steel weldment was studied more thoroughly than any of the other heat-resistant joints. Initial welding studies were made using a weld tip with a $^5/_{16}$-in. radius and an anvil with a 3-in. radius surface. This weld tip caused severe deformation of the weldment and contributed to the cracking shown in Fig. 2. Even though cracking was found in nearly all welds made using the $^5/_{16}$-in. radius weld tip, relationships were found between weld strength and tip displacement, clamping force, and weld time. These relationships are shown in Fig. 3. Shown in the tip-displacement vs. weld-strength figure are the effects of welding with either the titanium (Curve 1) or the stainless steel (Curve 2) under the weld tip. As can be seen, the material under the weld tip had no effect on the joint strength. Also shown is the effect of welding this joint with a 3-in. radius weld tip (Curve 3).

One fact was noted when the bond area of the fractured tensile-shear specimens was measured. There appeared to be an optimum weld area at which the highest weld strengths were experienced. Strengths increased linearly with bond area to the optimum and then dropped off, probably due to severe cracking at conditions which produce a larger apparent bond area. In nearly all welds made between titanium and stainless steel at high tip displacements and utilizing the $^5/_{16}$-in. tip radius, slivers of titanium were extruded out from the bond in a direction normal to the direction of tip displacement. This is illustrated by Fig. 4. Metallographic examination of these slivers indicate they were titanium. The titanium was heated during the weld cycle to a temperature at which it had become highly plastic so that material could be extruded out from the periphery of the bond area. It will be noted that in the central area of the bond the original sheet surface is still intact and the titanium surface is imprinted on the stainless steel surface. The annular area surrounding this central zone is the area in which the clamping pressure was low enough to allow slippage.

(a) Titanium (top) to 316 stainless steel (bottom). Etchant: 5 HF, 10 HNO_3, 30 actic, glycergia. X 30

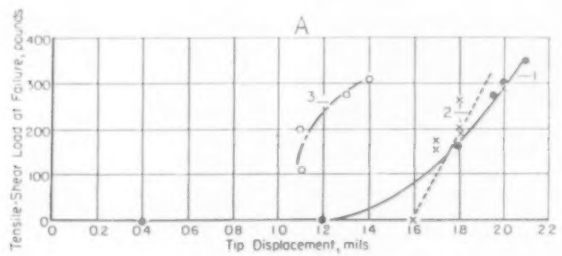
(b) Titanium to titanium. Etchant: 1.5 HF, 3.5 HNO_3, H_2O. X 30

(c) 316 stainless steel (top) to Mo-0.5% Ti (bottom). No etchant. X 30

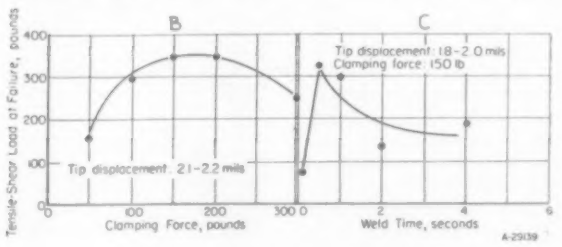
(d) Mo-0.5% Ti to Mo-0.5% Ti. Murakami's etchant. X 50

Figure	Tip displacement, mils	Clamping force, lb	Weld time, sec
a	1.7	150	2
b	1.6	200	1
c	1.4	200	3
d	1.2	300	0.5

Fig. 2—Examples of the cracking observed in ultrasonic welds in the heat-resisting alloys. (Reduced 55% on reproduction)



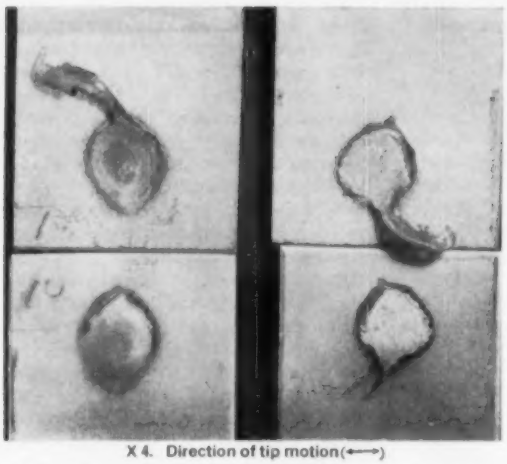
Curve	Weldment	Clamping force, lb	Weld tip Type	Weld tip Radius, in.	Anvil Type	Anvil Radius, in.
1	Ti to 316 stainless steel	150	1B	$^5/_{16}$	5	3
2	316 stainless steel to Ti	150	1B	$^5/_{16}$	5	3
3	316 stainless steel to Ti	200	1C	3	3	Flat



Data for graphs (B) and (C)

Weldment	Weld tip Type	Weld tip Radius, in.	Anvil Type	Anvil Radius, in.
Ti to 316 stainless steel	1B	$^5/_{16}$	5	3

Fig. 3—Variation in weld strength with tip displacement, clamping force, and weld time for welds between 0.020-in. titanium and 0.018-in. AISI 316 stainless steel. Weld time: 1 sec.



X 4. Direction of tip motion(⟷)

(a) 316 stainless steel to titanium

(b) Titanium to 316 stainless steel

Fig. 4—Fractured ultrasonic welds between titanium and AISI 316 stainless steel showing metal which was extruded out from the weld area during welding. (Tip displacement, 1.8–2.0 mils; clamping force, 150 lb; weld time, 1 sec.; tip radius, $^5/_{16}$ in.)

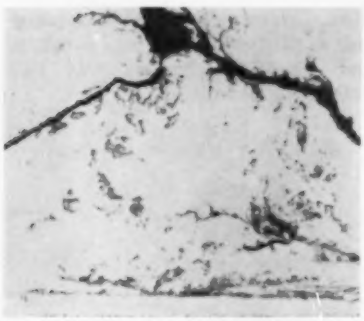
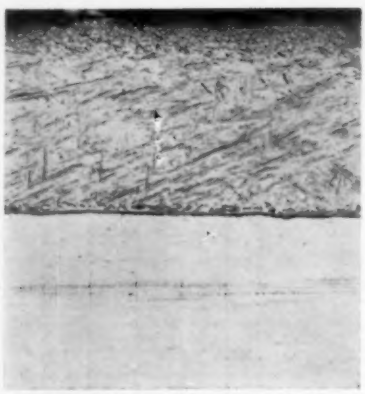


Fig. 5—Structure at the edge of an ultrasonic weld between titanium (above crack) and AISI 316 stainless steel showing cracks and the second phase found in this type of weldment. (Tip displacement, 3.1 mils; weld time, 1 sec; clamping force, 150 lb.; tip radius, $^5/_{16}$ in). Etchant: 1 HF, 30 HNO_3, 30 lactic. X 500. (Reduced approximately 50% on reproduction)



(a) Tip displacement, 1.3 mil; clamping force, 150 lb.; weld time, 4 sec.; tip radius, $^5/_{16}$ in. Etchant: 5 HF, 10 HNO_3, 30 lactic. X 100

(b) Typical interface, tip displacement, 2.1 mils; clamping force, 150 lb.; weld time, 1 sec. tip radius, $^5/_{16}$ in. Etchant: 1 HF, 30 HNO_3, 30 lactic. X 700

Fig. 6—Central portion of the interface of ultrasonic welds between titanium (above line shown) and AISI 316 stainless steel

Some welds were made between the titanium and stainless steel using a weld tip with a 3-in. radius tip surface. The effect of this weld tip on weld strength is shown graphically in Fig. 3A. Larger bond areas with less cracking were obtained when a 3-in. radius weld tip was employed. The ratio of cross-tension strength to tensile-shear strength for this weldment was about 0.1.

Extensive metallographic examinations were made of the titanium to stainless steel weldment. Of particular interest was the area near the edge of the bond where cracking took place. A second phase was found in the titanium in the areas surrounding the cracks. This is shown in Fig. 5. This phase has been identified as titanium hydride. If this is so, hydrogen embrittlement may be contributing to the cracking of these joints. Hydrogen may migrate from cooler unstressed titanium to the warmer highly stressed areas at the edge of the bond. Other investigators have commented on the breakup of pearlite and the diffusion of carbon in welding low-carbon steel.[6] The hydrogen content of this sheet was reported as 97 ppm, which is below the amount to cause embrittlement in fusion welds. If this analysis is correct, the hydrogen content of titanium is much more critical for ultrasonic welding.

Shown in Figs. 6a and 6b are the titanium-stainless steel interfaces for two welds. It will be noted from the acicular microstructure of the titanium in Fig. 6a that the titanium had been heated into the beta range during welding. This indicates interfacial temperatures exceeding 1600° F for this weldment. As can be seen from Fig. 6a, there appeared to be a film in the interface and a second phase could be seen paralleling the interface. The phenomenon of the apparent film has not been explained, unless it represents metal which had been molten or alloying which occurred during welding. The precipitate paralleling the interface was not identified. This may be a product of diffusion which might have occurred in this sample. A 4-sec weld time was utilized for this joint. This is a much longer weld time than normally used and may have allowed time for diffusion to take place. These phenomena were not seen in other titanium to AISI 316 stainless steel welds. Figure 6b shows a more typical interface. The titanium was etched very lightly for this photograph so the acicular titanium microstructure is not apparent. The interface was very irregular and several areas could be found in which "laps" of stainless steel could be seen in the titanium. Apparently, considerable deformation took place at the interface. This micrograph was taken near the center of the same weld pictured in Fig. 5.

Titanium to Titanium

During the course of the study the weldments containing titanium several titanium-to-titanium welds were made with the purpose of determining whether the second phase found in joints containing stainless steel was due to the pres-

ence of stainless steel. The second phase also was noted in the titanium-to-titanium welds, especially at the edge of the bond where cracking took place. Ultrasonic welds in titanium had tensile-shear breaking loads of 440 lb and cross-tension loads of 105 lb giving a cross-tension to tension-shear strength ratio of 0.240. Failures occurred by shearing the weld nugget from both sheets. These values are equivalent to those expected from resistance spot welds in this type and thickness of titanium.[5]

Figure 2b is a macrograph of a titanium-to-titanium weld showing the cracking which took place during welding. The darkened area represents the heat-affected zone in which the titanium was heated into the beta range during welding. Figure 7 shows the central portion of the bond in Fig. 2b. Note the deformation and the second phase which was present near the interface.

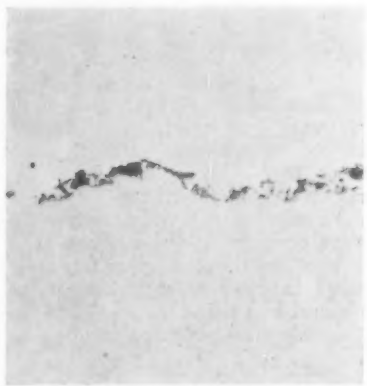
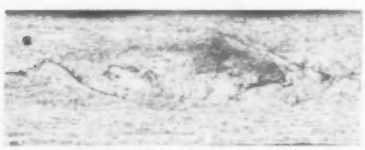
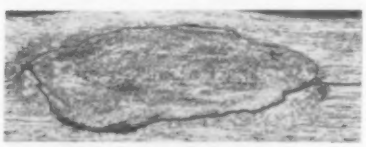


Fig. 7—Micrograph of the central portion of the interface of an ultrasonic weld in titanium. (Tip displacement, 1.6 mils; weld time, 1 sec.; clamping force, 200 lb.; tip radius, $^5/_{16}$ in.) Etchant: 1 HF, 30 HNO_3, 30 lactic. X 250



(a) Section parallel to direction of tip motion. Murakami's etchant. X 50



(b) Section normal to direction of tip motion. Murakami's etchant. X 50

Fig. 8—Ultrasonic welds in molybdenum-0.5% titanium alloy. (Reduced approximately 50% on reproduction)

Molybdenum to Molybdenum

The material utilized for this study was 0.015-in. thick molybdenum, 0.5% titanium alloy. Microhardness data for the base metal indicated cold reduction in excess of 80%. Welding was accomplished using a welding tip with a 3-in. radius surface in conjunction with a flat anvil.

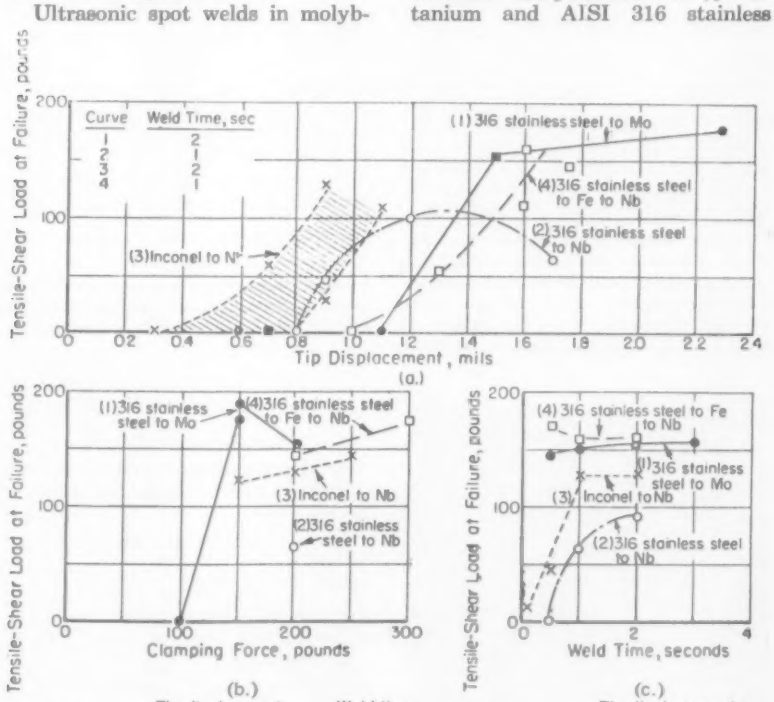
Tip displacements were varied from 0.7 to 1.6 mil at clamping pressures between 200 and 300 lb and at weld times from 0.5 to 2 sec. The properties of the joints formed were very erratic and strengths were extremely low. Figure 8 shows some welds in molybdenum. The extent of the internal deformation in molybdenum welds was much greater than for any other material studied. Molybdenum possessed the highest modulus of elasticity, meaning that given strains were accompanied by higher stresses than for the other materials studied. Existence of these high stresses may explain the greater amount of deformation found in this weldment. The great degree of cracking in molybdenum is probably related to the low elongation found in molybdenum.

Ultrasonic spot welds in molybdenum were very weak. Tensile-shear loads at failure were generally below 60 lb and cross-tension loads were nil. The best welds were produced at 1.15-mil tip displacement, 300-lb clamping force and 2-sec weld time. Other investigators also have noted low strengths and extensive interior deformation for ultrasonic spot welds in molybdenum.[6] This low strength is to be expected from examination of microsections, as shown in Fig. 8. The molybdenum used during this investigation possessed a very rough surface. If the surface were polished or the gross roughness were removed, improvement in weldment properties might result. Further improvements in molybdenum weldments might be realized by:

1. The use of preheat to lower mechanical properties and increase ductility.
2. The use of high clamping pressures.
3. The use of more rapid energy input.

Molybdenum to AISI 316 Stainless Steel

A study of the effect of tip displacement, clamping force and weld time on the strengths of welds between molybdenum—0.5% titanium and AISI 316 stainless


Tensile-Shear Load at Failure, pounds
Curve
Weld Time, sec
1 2
2 1
3 2
4 1
(1) 316 stainless steel to Mo
(4) 316 stainless steel to Fe to Nb
(2) 316 stainless steel to Nb
(3) Inconel to Nb
Tip Displacement, mils
(a.)
(1) 316 stainless steel to Mo
(4) 316 stainless steel to Fe to Nb
(3) Inconel to Nb
(2) 316 stainless steel to Nb
Clamping Force, pounds
(b.)
(4) 316 stainless steel to Fe to Nb
(1) 316 stainless steel to Mo
(3) Inconel to Nb
(2) 316 stainless steel to Nb
Weld Time, seconds
(c.)

Curve	Tip displacement, mils	Weld time, sec
1	1.5	2
2	1.7	1
3	0.9–1.0	2
4	1.7–1.75	1

Curve	Tip displacement, mils
1	1.5
2	1.7–1.8
3	0.6–0.8
4	1.5–1.6

Fig. 9—Variation in weld strength with tip displacement, clamping force, and weld time for welds between AISI 316 stainless steel and molybdenum, AISI 316 stainless steel and columbium, Inconel and columbium, and AISI 316 stainless steel and iron and columbium. Clamping force of 200 lb for (a) and (c)

steel was made. The effect of these variables on weld strength is shown in Fig. 9. In many instances, the tensile-shear fracture occurred by tears along the laminations in the molybdenum sheet. Laminations are common in all molybdenum sheet which has been severely cold worked. Tensile-shear loads up to 190 lb were determined for the joint, although loads in the neighborhood of 160 to 170 lb were more common. Cross-tension strengths were nil.

Cracking of the molybdenum was a problem associated with this weldment. The type of cracking is shown in Fig. 2c. This cracking appeared to consist of opening up the laminations in the sheet. A typical weld interface is shown in Fig. 10. The interface was nearly an unbroken line. No diffusion or formation of intermetallic compounds were found in any section examined. In this joint, sliding apparently took place over the entire bond area during welding, removing the asperities of the molybdenum and stainless steel accounting for the rather smooth joint formed.

Fig. 10—Central portion of the interface of an ultrasonic weld between AISI 316 stainless steel (top) and molybdenum-0.5% titanium alloy. (Tip displacement, 1.4 mils; clamping force, 200 lb.; weld time, 3 sec.) Murakami's etchant. X 500

Fig. 11—Central portions of the interface of an ultrasonic weld between AISI 316 stainless steel (top) and columbium. (Tip displacement, 1.7 mils; weld time, 1 sec.; clamping force, 200 lb.) Etchant: 5HF, 10 HNO_3, 30 lactic. X 500

Columbium to AISI 316 Stainless Steel

Several welds were made to determine the room-temperature properties of the columbium to AISI 316 stainless steel weldment. Few data were available to determine the relationship between weld strength and the welding variables. The available data, however, are plotted in Fig. 9. Highest strength welds were produced between columbium and stainless steel at approximately 1.2-mil tip displacement, 200-lb clamping force and 1-sec weld time. Maximum tensile-shear loads of the columbium-stainless steel joint were in the neighborhood of 90 to 100 lb and cross-tension loads were about 5 lb.

Metallographic examinations indicated cracking was not so serious a problem as in other joints under study, although some cracking did occur. Figure 11 shows the interfact of the weldment. The softer columbium can be seen flowing into the depressions in the stainless steel surface. The columbium in the neighborhood of the interface was plastically deformed during welding. The center portion of the bond area apparently was nearly stationary during welding, since the imprint of the stainless steel could be clearly seen on the columbium surface. Slippage took place in the area surrounding the central portion of the bond.

Columbium to Iron to AISI 316 Stainless Steel

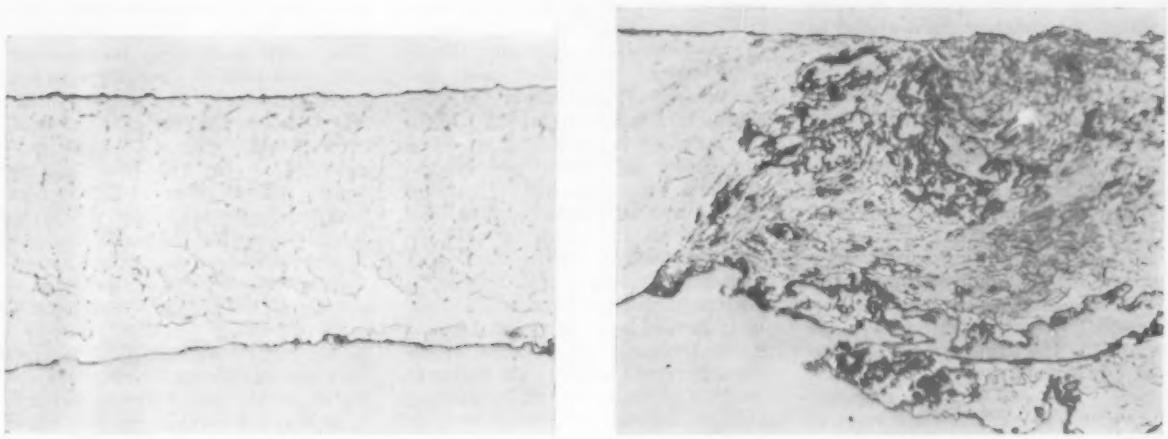
The columbium to high-purity iron to AISI 316 stainless steel weldment was made in one operation. This was the easiest of all heat-resistant weldments to produce. As in the case of the other weldments, the effects of tip displacement, clamping force and weld time on weld strength were determined. The results are shown graphically in Fig. 9. Optimum weld strengths were obtained at about 1.5-mil tip displacement, 200- to 300-lb clamping force and 0.5-sec weld time. Tensile-shear loads at failure of 160 to 175 lb were obtained with cross-tension loads of about 50 lb. The ratio of cross-tension to tensile-shear strength for this weldment was 0.286. From the data given in Table 3, it can be seen that the use of the iron insert improves the properties of the stainless steel to columbium welds, especially the cross-tension strength. Iron was used primarily because it is believed to be a barrier to diffusion which might occur between columbium and stainless steel. At these strength values, failure occured by tearing the nugget from the iron on both the columbium and iron interfaces. This improved cross-tension strength indicates that a good bond was attained at both interfaces

Failures of this joint nearly always occurred at the stainless steel to iron junction. Further improvement in joint strength might be realized by plating the iron onto the stainless steel prior to welding to

Table 3—Summary of Tensile-Shear and Cross-tension Strengths of Welds Made During This Investigation

Weldment[a]	For weldments produced at same condition: Tensile-shear load at failure, lb	Cross-tension load at failure, lb	Ratio cross-tension load, tensile-shear load	Maximum tensile-shear load obtained, lb
Aluminum to aluminum (1100-H18, 0.040 in. thick)	445	85	0.191	500[e]
Gold to gold	175[b]	...	...	175[b]
Titanium to AISI 316 stainless steel	200	20	0.100	350
Titanium to titanium	440[e]	105[c]	0.240	440[c]
Molybdenum to molybdenum	60	Nil	Nil	60
Molybdenum to AISI 316 stainless steel	120	10	0.0834	190
Columbium to AISI 316 stainless steel	90	5	0.056	100
Columbium to iron to AISI 316 stainless steel	175[d]	50[d]	0.286	175[d]
Columbium to Inconel	125	10	0.080	145

[a] All material was 0.015–0.20 in. thick except as noted.
[b] Failed by tearing of gold sheet adjacent to the bond.
[c] Failed by shearing the nugget from both sheets of titanium.
[d] Iron was pulled out on both the niobium and stainless steel.
[e] No failure; this was the limit of the testing machine used.



(a) (b)

Fig. 12—Ultrasonic welds between AISI 316 stainless steel (top) and high-purity iron (middle) and columbium (bottom). (Tip displacement, 1.7 mils; clamping force, 300 lb.; weld time, 1 sec.) Etchant: 5 HF, 10 HNO_3, 30 lactic. X 500 (Reduced about 30% on reproduction)

produce a better bond at the stainless steel to iron interface. Again, it was apparent that sliding did not take place in the central zone of the bond area and slippage took place in the annulus surrounding this central zone, although this area was smaller than for the stainless steel to columbium welds.

Metallographic examination did not show any evidence of cracking in this joint. Evidently, the iron absorbed the strain so as to prevent cracking of the columbium. Figure 12a is a micrograph of the columbium to iron to AISI 316 stainless steel weld near the center of the bond. Good bonds were apparently obtained at both interfaces. The 0.005-in. thick high-purity iron sheet possessed a severely cold-worked structure prior to welding. The iron in this joint had been recrystallizing during welding, indicating that interfacial temperature exceeded 800° F.[9] Figure 12b shows the same weld near the edge of the bond. At this location, the iron has been severely cold worked and the columbium surface has been broken up. Pieces of columbium can be seen in the iron even in the vicinity of the stainless steel surface. If melting did not take place in this area, this indicates that extremely high alternating stresses are found in this area of an ultrasonic weld and that the iron was in a highly plastic condition.

Columbium to Inconel

Columbium-Inconel welds were made to determine the effect of welding variables on the properties of joints. The effect of the welding parameters are shown in Fig. 9. Highest strength welds were produced at about 1.0-mil tip displacement, 250-lb clamping force, and 2-sec weld time. Tensile-shear loads in the neighborhood of 130 to 145 lb were common, while cross-tension loads were about 10 lb.

Metallographic examinations indicated severe cracking of the columbium at the edge of the bond area. The cracks were normal to the sheet surface and had the appearance of being tears in the sheet which might be expected in a ductile metal such as columbium. Figure 13 shows the interface near the center of the bond. This joint appeared to be very similar to the columbium-stainless steel joint in appearance. The softer columbium was partially forced into the depressions in the Inconel surface.

The appearance of the fracture face in this joint was similar to that found in the columbium-stainless steel welds. Apparently, little or no relative sliding occurred at the center of the bond, since the Inconel surface was imprinted on the columbium. Slippage did occur in the annulus surrounding the central portions.

Discussion

The major problem encountered in the welding of the heat-resistant materials was the presence of cracks in the majority of welds. The presence of the cracks was not apparent as long as only tensile-shear samples were tested. Only metallographic examination showed the presence of the cracks and indicated the seriousness of the problem. Cracking was also noted in aluminum ultrasonic welds when the tip displacement was exceedingly high (about 2 mils or more). This is probably due to the lower modulus of elasticity of aluminum. Aluminum can withstand a greater strain without failure than can the heat-resistant materials. Cracking always took place at the edge of the bond area where the highest and most concentrated stresses would be developed.

Part of an investigation of the friction of rubber was the determination of the cause of tears appearing in the rubber when a spherical surface slid on a flat rubber surface.[10] Investigators found by using photoelastic models that the stress was concentrated at the rear of the area of contact as a tangential force was exerted on the sphere. It was shown that the stress at the point of concentration must be predominantly tension in nature and that failures due to frictional stresses would be expected

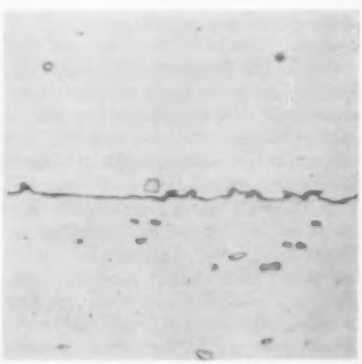


Fig. 13—Central portion of the interface of an ultrasonic weld between Inconel (top) and columbium (bottom). (Tip displacement, 0.6 mil; weld time, 2 sec.; clamping force, 200 lb.) Etchant: 3 HF, 10 HNO_3, 30 lactic. X 500

to consist of the opening of tears behind the slider at right angles to the direction of sliding.

During one-half of a cycle in ultrasonic welding, a tear might be opened due to tension stresses at the sheet surface, if the strain is sufficiently high. The crack may then propagate as a fatigue failure during the remainder of the weld time. Metallographic examinations indicated that the degree of cracking increased with tip displacement and weld time and was independent of clamping pressure in the range studied. Tip displacement governs the amount of stress present at the edge of the weld area. If displacement were lowered below a value at which a crack will form, strong bonds might be obtained at higher clamping pressures and slightly longer weld times. Cracking also was lessened by the use of larger tip radii. Higher powers and clamping forces than those used in this work might aid in eliminating cracking.[11]

The great amount of deformation which took place during the welding of molybdenum was not readily explained. This study indicated the need to investigate further the effects of mechanical properties of the materials being welded. It appeared that the amount of deformation might be related to the modulus of elasticity, since deformation appeared to increase with increasing modulus.

One reason for an interest in the use of ultrasonic welding of heat-resisting metals was the possible welding of dissimilar metal combinations with no formation of brittle intermetallic compounds. No intermetallic compounds were noted in the welds examined metallographically. Diffusion and formation of intermetallic components might occur in some of the joints if they were subjected to elevated temperature for extended periods of time.

One other factor worth noting in connection with most of the ultrasonic welds in heat-resisting alloys studied during the program was the low cross-tension strength. Unless this cross-tension strength is raised, it is difficult to see any wide application of ultrasonic welding to dissimilar metal joints in heat-resisting alloys for aircraft use. The cross-tension as well as the tensile-shear strength of the joint between stainless steel and columbium was greatly improved by placing an iron insert in the interface. Low-strength welds in the stainless steel to columbium weldment may have been a result of the difference in mechanical properties. Ultrasonic energy may have been dissipated by deformation of the columbium without causing sliding to take place in the interface. The iron insert may have lessened the gradient in mechanical properties and allowed sufficient sliding to take place at the interface to produce good metal-to-metal contact and thus form a strong weld. Molybdenum-to-molybdenum joints may be improved by placing a soft metal foil in the interface. Several investigators have improved the pressure welding of molybdenum by placing foils of metals such as nickel or tantalum in the interface.[12, 13]

Another factor not studied in this investigation was the determination of fatigue properties of dissimilar metal weldments. In the few attempts to produce multiple spot welds in small specimens, initial welds were broken when attempting to make subsequent spot welds. It appears that ultrasonic welding may be readily adapted to the welding of soft metals such as aluminum, but that further research is required before useful dissimilar metal joints are produced in heat-resisting alloys.

Summary

The joining of selected material combinations by ultrasonic welding were studied. The combinations studied were:

1. Titanium to AISI 316 stainless steel
2. Titanium to titanium
3. Molybdenum to molybdenum
4. Molybdenum to AISI 316 stainless steel
5. Columbium to AISI 316 stainless steel
6. Columbium to iron to AISI 316 stainless steel
7. Columbium to Inconel

Ultrasonic welds in these heat-resisting and refractory alloys generally contained cracks at the edges of the bond area. Only the stainless steel to iron to columbium weldments could be made crack free. These cracks appear to be fatigue cracks caused by the high alternating stresses present at the edge of the weld area during welding. Methods have been proposed to eliminate the cracking problem and allow ultrasonic welding to be used to joint these materials. No intermetallic compounds were found in dissimilar metal weldments.

Table 3 summarizes some of the properties of weldments made during the course of this investigation. The welds comparing tensile-shear and cross-tension strength were not made necessarily at optimum welding conditions. As can be seen, cross-tension strengths were generally low in the heat-resisting welds. The titanium-to-titanium and stainless steel to iron to columbium weldments possessed acceptable cross-tension strengths. Cross-tension ratios for the titanium-to-titanium welds were comparable with the ratio obtained from resistance spot welds.[8] The highest tensile-shear strengths obtained are noted in the last column. Aluminum and gold welds are also listed to indicate the ease of welding and the properties obtainable in soft metals such as these.

Acknowledgment

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Welding the Beta Titanium-Base Alloy Ti–13V–11Cr–3Al

One of four methods may be selected to obtain high strength welds with ductilities comparable to the parent metal

BY H. D. KESSLER

Introduction

Ti – 13V – 11Cr – 3Al, a metastable beta type titanium-base alloy is one of the most versatile and efficient structural materials available today. In the annealed condition it is highly ductile and readily formable. Being highly alloyed (27% by weight), air cooling from solution-annealing temperatures of 1400–1450° F retains the soft dispersion-hardenable beta phase. Large increases in strength, to over 200 ksi, can be obtained by simple aging for 25–100 hr at temperatures from 800 to 900° F. These characteristics make the alloy attractive for aircraft and missile applications such as aircraft skins, stiffeners, pressure vessels and structural members, in the −65 to 600° F temperature range.

Many of the proposed applications for this alloy require welding during some phase of fabrication. Therefore, the Titanium Metals Corporation of America instituted an investigation to determine procedures that would produce the optimum combinations of aged strength and ductility in fusion weldments of the alloy. Various phases of this work included the heat treatment of welds on annealed and/or aged material, the effects of repair welding, and the benefits gained by cold working the welded area. The results of this program are summarized here.

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Welding Conditions

Titanium weld zones must be protected from the atmosphere since oxygen, nitrogen and hydrogen are highly soluble in hot and molten titanium.

Much of the early welding of titanium was carried out in enclosed chambers under a complete blanket of inert gas. This technique is still preferred in production runs of small parts or complex shaped weldments. For the most part, however, "open-air" welding is very adaptable to production operations—particularly in applications involving large structures—and is accomplished through use of inert-gas shielding of gas-shielded arc regions with a combination of inert-gas trailing shields and inert-gas back-up shielding.

The weld puddle and adjacent heat-affected zones on the face of the weld are protected by the nozzle gas. The trailing shield is used to protect the hot solidified metal and heat-affected zones behind the weld puddle, and the back-up shielding protects the root of the weld and its adjacent heat-affected zones. Titanium welding requires larger gas nozzles for primary shielding of the weld puddle and heat-affected zone than do steel or aluminum. For titanium, a $^{9}/_{16}$-in. gas nozzle is generally used with a $^{1}/_{32}$-in. tungsten electrode.

Typical settings used on 0.062-in. material are listed as follows:

Welding current, amp	80–100
Arc voltage, v	9–11
Carriage travel speed, in./min	8–10
Argon for arc shield, cfh	15
Argon for trailing shield, cfh	35
Helium for root shield, cfh	3–5

Note on Testing Procedures

A problem encountered in testing welds on materials such as the heat-treatable titanium alloys with a 100% weld joint efficiency is that the samples fail in the parent metal before the yield strength of the weld area is reached. To force the fracture to take place in the weld, a sample configuration was used with a reduced section as shown in Fig. 1. The tensile elongation was measured over a $^{1}/_{2}$-in. gage length, 75 to 85% of which was composed of weld and heat-affected metal. Correlation tests on parent metal in the 160 ksi yield strength range showed the yield strengths of the reduced section samples to be approximately 5–8 ksi higher than those using the standard 2-in. gage length; however, the tensile elongations of the two agreed very favorably. During heat treatment, an oxide formed on the weldments which was removed by vapor blasting and pickling in an HNO_3-HF (10 : 1) acid bath for 10–15 sec.

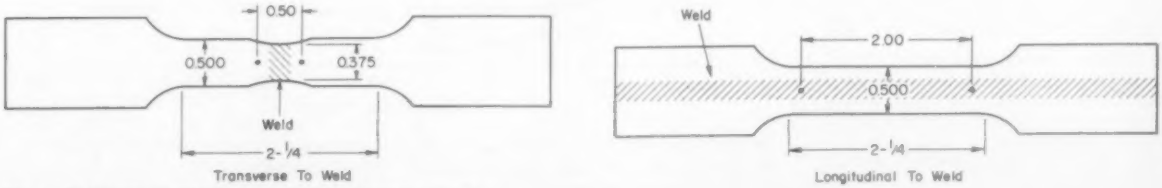

Fig. 1—Specimen configurations used for testing welds

Welding Beta in the Annealed Condition

Joint efficiencies of greater than 100% are obtained along with excellent tensile and bend ductilities. Contrary to normal expectance, annealing has an adverse effect on these ductilities. Figures 2 and 3 are photomicrographs of the weld metal before and after annealing. The matrix structure in the two photomicrographs is the ductile beta phase of titanium. An exact identification has not, as yet, been made of the precipitate; however, it is believed to be alpha phase rejected during the cooling or heat treating operation. The grain boundary structure, shown in Fig. 3, which develops on annealing is probably responsible for the loss in ductility during this operation. No such precipitate forms in the base metal upon annealing. Hardness variations between these microstructures are not significant.

The rates at which the weld, heat-affected zone, and parent metal respond to heat treatment are factors that must be considered before an optimum heat treatment for the weldment can be selected. Figure 4 shows that at 900° F both areas age at essentially the same rate, but that the tensile ductility of the welded area is 40–50% that of the parent metal; for this reason the direct simple aging of weldments is not recommended. It is believed that the low ductility of the aged weld metal is related to microsegregation, which occurs during the solidification process. Upon aging, this microsegregation results in non-uniform hardening and embrittlement at or near the grain boundaries.

Duplex Aging of Welds

Complex aging treatments have been found to produce excellent combinations of strength and ductility in weldments of the alloy. However, single, duplex or triplex aging treatments, where the lower temperature treatment is the final operation of the sequence, produce welds with poor tensile ductilities. The proper sequence is to first age the weldment at a lower temperature, and then follow this with a higher temperature over age. Figures 5 and 6 show that progressively higher strength levels with slightly lower ductilities are obtained by preaging at 900° F for 30 and 60 hr, and then overaging for various intervals at 1100, 1050 and 1000° F, respectively. These figures generally show that the higher the final aging (actually overaging) temperature, the lower the strength level; but the higher the ductility of both the weld and the parent metal. The 60-hr preaging treatment results in about 5–10,000 psi higher strength levels in both the weld and the base material. For the duplex treatments used, tests of welds perpendicular to the axis of loading were generally 5–10,000 psi higher in strength than welds tested parallel to the axis of loading. This, undoubtedly, is a reflection of the fact

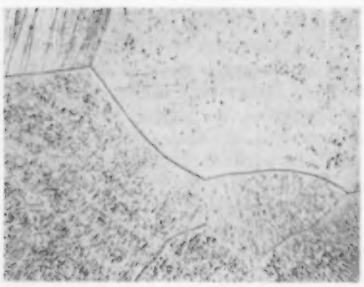

Fig. 2—Structure of weld metal on annealed material as welded. Ultimate tensile strength—141.8 ksi; 0.2% yield strength—135.1 ksi; elongation (% in 1/2 in.)—16.0. X 500. (Reduced approximately 50% on reproduction)

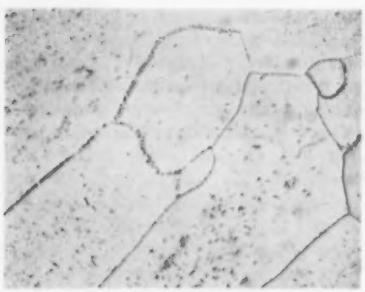

Fig. 3—Structure of weld metal on annealed material after solution annealing, 1500° F (10 min) AC. Ultimate tensile strength—138.0 ksi; 0.2% yield strength—136.7 ksi; elongation (% in 1/2 in.)—10.0. X 500. (Reduced approximately 50% on reproduction)

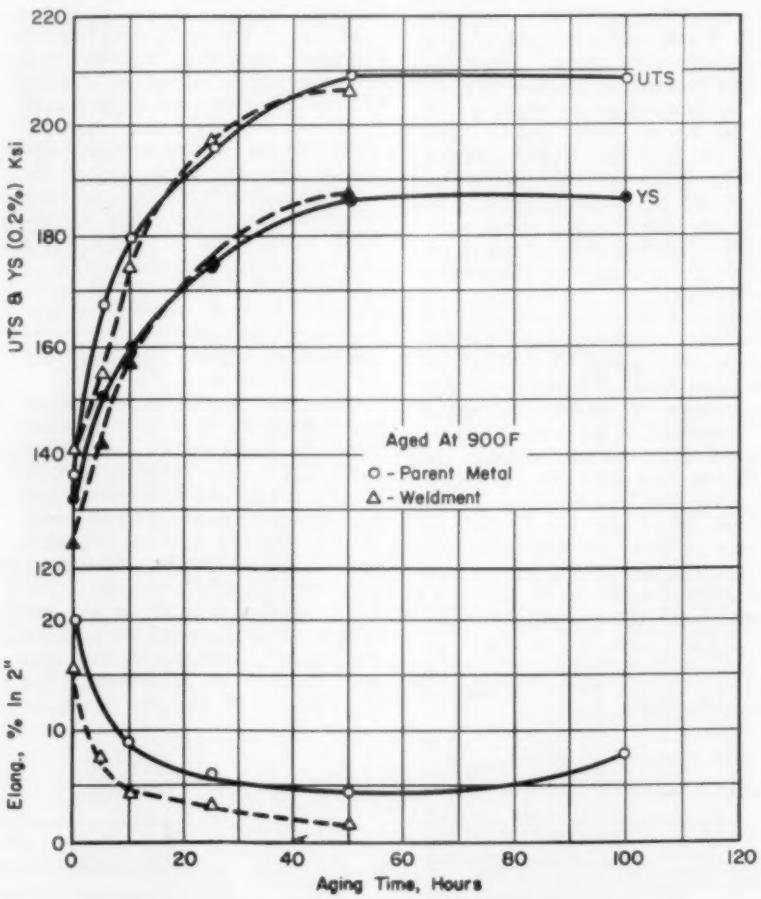

Fig. 4—Comparison between the aging response of the parent metal and weld zone of fusion welded 0.062 in. thick Ti – 13V – 11Cr – 3Al. Weld parallel to the axis of loading

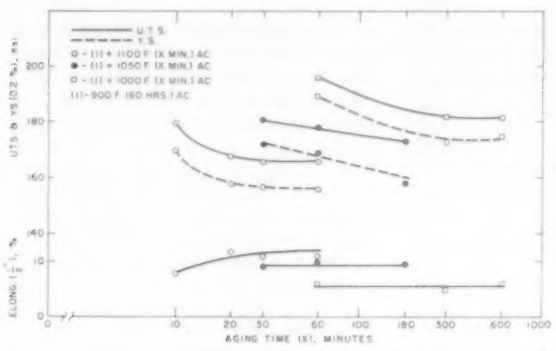

Fig. 5—Effect of postweld duplex aging treatments in tensile properties of fusion welded 0.062 in. thick Ti – 13V – 11Cr – 3Al; welds perpendicular to axis of loading

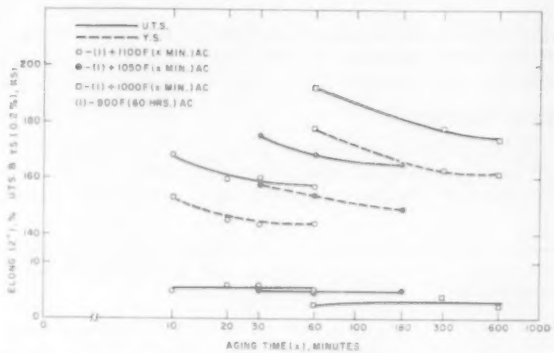

Fig. 6—Effect of postweld duplex aging treatments on tensile properties of fusion welded 0.062 in. thick Ti – 13V – 11Cr – 3Al; weld perpendicular to axis of loading

that some of the lower strength parent metal was included in the test section of samples in which the welds were parallel to the axis of loading. The parent metal yield strengths in the duplex heat-treated condition were generally 5–10,000 psi lower than those of the respective welds perpendicular to the axis of loading, as noted in Figs. 5 and 6.

Yield strength levels of interest to the designer and welding fabricator may be classified in ranges about 150, 170 and 190 psi. Recommended treatments to obtain these levels are as follows:

1. 150 Ksi: 900° F (30 hr) AC +1050° F (30 min) AC
2. 170 Ksi: 900° F (60 hr) AC + 1050° F (1 hr) AC
3. 190 Ksi: 900° F (30 hr) AC +1000° F (1 hr) AC

Good properties are obtained by overaging at 1100° F (10 min) AC, but the time at temperature is critical and too short for most commercial applications.

As a measure of the material's ability to yield locally in a notched area and to redistribute the imposed stresses before fracture occurs, room temperature notch ($K_t = 4$) tensile studies were made on the weld and parent metal of duplex aged weldments. The notched tensile strength ratios of the weld and parent metal were found to be approximately the same and equal to one (1.0) or better, as shown in Table 1. These results indicate that the notch sensitivity of the annealed parent metal is best of all the conditions tested, being somewhat greater than that of the as-welded weldment. The notch sensitivity of the aged or duplex-aged weldments and the aged parent

Table 1—Room Temperature Notch Tensile Properties of the Parent Metal and Welds on 0.062 In. Ti – 13V – 11Cr – 3Al

	Weld			Parent metal		
Condition	Notch ratio[a]	Yield strength (0.2%), ksi	Elongation ($^1/_2$ in.), %	Notch ratio[a]	Yield strength (0.2%), ksi	Elongation (2 in.), %
As-welded	1.19 = 168.0 / 141.2	134.8	16.0	...	...	..
Parent metal[b]	....	...	...	1.23 = 169.8 / 138.0	132.0	20.0
+900° F (60 hr) AC	[c]	[c]	[c]	1.11 = 194.3 / 177.3	156.0	9.5
+900° F (60 hr) AC; +1050° F (30 min) AC	1.06 = 192.4 / 180.6	172.2	8.8	0.97 = 172.2 / 178.8	161.9	9.3
+900° F (60 hr) AC; +1050° F (1 hr) AC	1.08 = 192.1 / 177.0	168.9	10.0	1.07 = 186.5 / 174.5	157.6	10.5
+900° F (60 hr) AC; +1050° F (3 hr) AC	1.11 = 192.3 / 173.0	165.5	8.8	1.12 = 192.8 / 172.8	154.7	11.0

[a] Kt = 4. [b] In the annealed condition. [c] No value because a yield point could not be determined.

Table 2—The Effect of Postweld Heat Treatment on the Tensile Properties of Repair Welds on 0.062 In. Ti – 13V – 11Cr – 3Al

Condition	Weld angle to test, deg	Ultimate tensile strength, ksi	Yield strength (0.2%), ksi	Elongation (2 in.), %	Elongation ($^1/_2$ in.), %
As-welded	90	140.5	134.7	..	15.0
As-welded	0	130.4	118.3	14.8	..
Weld + anneal[a]	90	140.5	135.3	..	8.0
Weld + anneal[a]	0	133.8	126.8	7.5	..
W[b] + 900° F (30 hr) AC +1050° F (30 min) AC	90	158.4	153.9	..	5.0
W[b] + 900° F (30 hr) AC +1050° F (30 min) AC	0	168.7	156.2	6.0	..
W + 900° F (30 hr) AC +1050° F (1 hr) AC	90	162.6	156.3	..	6.0
W + 900° F (30 hr) AC +1050° F (1 hr) AC	0	164.3	150.4	6.5	..

[a] 1500° F (15 min) AC. [b] Denotes weld made on material in the annealed condition.

metal are essentially equal, at least for the notch factor of 4 that was used.

Repair Welding

Repair welding can cause many problems because of the complex metallurgical changes imposed on the weld area. Repair welding of the beta alloy is permissible and practical. Table 2 illustrates the results of tests on simulated repair welds, i.e., actually double-fusion pass welds. The as-welded tensile properties are comparable to those of single-pass welds; however, there is a slight loss in bend ductility. The aging response of the double-pass welds is less than that of the single-pass welds, but the strength levels are comparable. Exactly how these double-pass simulated repair welds, made on light gage 0.062-in. material, compare with similar welds made on plate is unknown as plate tests are currently in progress.

Table 3—The Effect of Cold Rolling (25% Reduction) on the Properties of Ti – 13V – 11Cr – 3Al Weldments

Condition	Ultimate tensile strength, ksi	Yield strength (0.2%), ksi	Elongation ($^1/_2$ in.), %
As-welded	141.2	134.8	16.0
Weld + CR[a]	157.1	145.2	10.0
Weld +900° F (60 hr) AC		Brittle fracture	
Weld + CR +900° F (60 hr) AC	205.8	203.0	3.0
Weld +900° F (60 hr) AC +1000° F (1 hr) AC	196.0	188.5	6.0
Weld + CR +900° F (60 hr) AC +1000° F (1 hr) AC	204.8	194.4	6.0
Weld +900° F (60 hr) AC +1050° F (1 hr) AC	177.6	168.7	10.0
Weld + CR +900° F (60 hr) AC +1050° F (1 hr) AC	187.0	177.9	6.0
Weld +900°F (60 hr) AC +1100° F (10 min) AC	179.4	169.8	8.0
Weld + CR +900° F (60 hr) AC +1100° F (13 min) AC	184.9	175.4	6.0

[a] Cold-rolled 0.062 in. sheet.

Effect of Cold Work on Weld Properties

Roll planishing, whereby the weld is mechanically cold worked, can be used to break up the cast structure, allowing the use of normal aging cycles to produce high strengths. Table 3 shows a comparison between the properties of cold-rolled (25% reduction) and noncold-rolled welds, and demonstrates three important facts:

1. Acceptable combinations of strength and ductility are obtainable by simple aging of cold-rolled welds.
2. Simple aging of worked material produces yield strengths of over 200 ksi.
3. Duplex aging of cold-rolled weldments results in a strength

Table 4—The Effect of Postweld Heat Treatment on the Tensile Properties of Fusion Welds on Partially Aged Ti – 13V – 11Cr – 3Al

Condition	Angle of weld axis to test, Deg	Type of sample	Ultimate tensile strength, ksi	Yield strength (0.2%), ksi	Elongation (2 in.), %	Elongation ($^1/_2$ in.), %	Fracture location
As-welded	90	Weld[a]	141.5	136.1	..	15.5	W.M.[d]
As-welded	90	Weld[b]	141.3	134.6	..	13.0	W.M.
As-welded	0	Weld	138.4	118.7	11.5	..	...
Partially aged	..	P.M.[c]	165.1	147.2	9.5	..	...
+900° F (30 hr) AC + 1050 F (30 min) AC	90	Weld[a]	171.6	162.4	..	8.0	W.M.
+900° F (30 hr) AC + 1050° F (30 min) AC	90	Weld[b]	171.8	156.9	..	12.0	W.M.
+900° F (30 hr) AC + 1050° F (30 min) AC	0	Weld	174.1	159.0	8.4	..	...
+900° F (30 hr) AC + 1050° F (30 min) AC	..	P.M.[c]	181.7	164.3	10.8	..	...
+900° F (30 hr) AC + 1050° F (1 hr) AC	90	Weld[a]	174.3	168.5	..	9.0	W.M.
+900° F (30 hr) AC + 1050° F (1 hr) AC	90	Weld[b]	173.5	158.3	..	14.0	W.M.
+900° F (30 hr) AC + 1050° F (1 hr) AC	0	Weld	172.5	157.4	10.5	..	...
+900° F (30 hr) AC + 1050° F (1 hr) AC	..	P.M.[c]	180.8	159.4	11.0	..	...
+900° F (30 hr) AC + 1050° F (3 hr) AC	90	Weld[a]	174.7	166.0	..	8.0	W.M.
+900° F (30 hr) AC + 1050° F (3 hr) AC	90	Weld[b]	172.1	157.9	..	10.0	W.M.
+900° F (30 hr) AC + 1050° F (3 hr) AC	0	Weld	173.4	156.4	7.5	..	...
+900° F (30 hr) AC + 1050° F (3 hr) AC	..	P.M.[c]	180.6	159.1	12.0	..	...
+900° F (60 hr) AC + 1050° F (30 min) AC	90	Weld[a]	180.1	172.6	..	7.0	W.M.
+900° F (60 hr) AC + 1050° F (30 min) AC	90	Weld[b]	181.5	161.6	..	12.0	W.M.
+900° F (60 hr) AC + 1050° F (30 min) AC	0	Weld	178.1	163.7	6.0	..	...
+900° F (60 hr) AC + 1050° F (30 min) AC	..	P.M.[c]	190.1	170.4	10.8	..	...
+900° F (60 hr) AC + 1050° F (1 hr) AC	90	Weld[a]	177.4	168.2	..	9.0	W.M.
+900° F (60 hr) AC + 1050° F (1 hr) AC	90	Weld[b]	174.3	161.1	..	12.0	W.M.
+900° F (60 hr) AC + 1050° F (1 hr) AC	0	Weld	176.1	161.8	8.3	..	...
+900° F (60 hr) AC + 1050° F (1 hr) AC	..	P.M.[c]	187.0	170.6	11.3	..	...
+900° F (60 hr) AC + 1050° F (3 hr) AC	90	Weld[a]	179.3	171.3	..	6.0	W.M.
+900° F (60 hr) AC + 1050° F (3 hr) AC	90	Weld[b]	175.4	160.7	..	11.0	W.M.
+900° F (60 hr) AC + 1050° F (3 hr) AC	0	Weld	175.6	156.3	6.8	..	...
+900° F (60 hr) AC + 1050° F (3 hr) AC	..	P.M.[c]	185.4	165.6	12.0	..	...

[a] Weld sample with a reduced section across the weld.
[b] Weld sample without a reduced section.
[c] Parent metal sample with roll parallel to the tensile axis.
[d] Weld metal.

advantage of 5–10,000 psi when compared to material that has been given the same duplex aging treatment but has not been cold rolled after welding, as illustrated in Table 4.

Welding of Aged Material

High strength welds with acceptable ductilities are obtainable by duplex aging, but the overaging cycle reduced the strength of the parent metal below that of the weld. To arrive at a better balance of strength levels, two approaches are possible:

1. The weld can be made on a built-up section of the assembly that has been preaged to the required strength. No further aging is necessary, as excellent properties are obtained in the as-welded condition and the increased weld cross-sectional area provides the increased strength to match that of the parent metal. This combination allows the use of a weld having maximum ductility.

2. As illustrated in Table 4, welding may be conducted on partially aged material, and the assembly subsequently duplex aged. Here, the parent metal was partially aged 10 hr at 900° F prior to welding. This resulted in a strength increase of approximately 15–20,000 psi. After welding and superimposing the various duplex aging cycles, parent metal and transverse weld tests showed yield strengths generally within 5000 psi of each other. The 900° F (60 hr) AC + 1050° F (1 hr) AC cool cycle produced the highest yield strengths and excellent ductilities.

Summary

High strength welds with ductilities comparable to those of the parent metal are obtainable on the Ti – 13V – 11Cr – 3Al alloy. The selection of the optimum welding procedure to produce these properties is governed by a number of factors, such as welding and handling facilities, fabricating sequence and size of the weldment. In conjunction with these, the fabricator has four possible choices from which to select the appropriate method of producing a high strength weldment. They are:

1. Weld the annealed components, and subject the assembly to a duplex aging cycle. High strength weldments with greater than 100% joint efficiency are produced.

2. Weld partially aged components, and subject the fabrication to a duplex aging cycle. With the proper selection of aging treatment, the strength of the weld and parent metal can be balanced.

3. Weld built-up sections of the fully aged components. The increased cross-sectional area of the weld will compensate for its lower strength level, and the weld will have maximum ductility.

4. Weld annealed components, roll planish the welds and simple age the assembly. Weldments with the highest possible strengths, over 200 ksi, are obtainable by this procedure.

EUROPEAN WELDING RESEARCH

(*Continued from page 350-s*)

Jezek, but it is difficult to arrive at satisfactory constants for the formulas.

USSR

Svarachnoe Proizoodsto contains the following articles in its October 1960 issue:

- Formulas are derived for the stress carried by each of the welds of a lap joint with transverse fillets in plates of unequal thickness.
- Hydrogen in weld metal is best analyzed by vacuum extraction at 1100° F. Hydrogen in pores is determined by solution.
- An improvement in the weldability of several grades of austenitic stainless steel was effected by remelting the steel in an electroslag consumable electrode remelting furnace with a water-cooled mold. The remelting reduced the inclusion content.
- Electroslag welds were made in steel 4-in. thick with steel plate electrodes 4-in. wide and 0.28- to 0.79-in. thick at 29–46 v, 600–1300 amp. The best voltage was 32 to 38, compared with 44–52 v for wire electrodes.
- Titanium and Type 347 stainless steel tubes $^{3}/_{16}$-to 1-in. diam 0.04-0.06-in. wall were butt welded in a condenser discharge machine. The Type 347 tubes were butt welded together with 7000 microfarads, 2000 v and 5600 lb force. The titanium tubes did not require pickling before welding.
- A semiautomatic gun for argon arc welding of aluminum alloys feeds two parallel electrodes $^{1}/_{16}$-in. diam spaced $^{3}/_{32}$-in. apart. Sound welds were obtained at 380 to 400 amp, compared with a maximum amperage of 320 for a single $^{5}/_{64}$-in. wire.
- A superior alloy for spot welding electrodes for aircraft longerons contains 99.20 Cu, 0.31 Cr and 0.29 Cd. It is quenched in water from 1760° F, aged 5 hr at 840° F and cold rolled 20–30% to 121-129 Brinell. The tip was flat and $^{5}/_{8}$-in. diam. The same alloy provided good service in projection welding.
- Seam welding of polyethylene film was performed at 780 in./min using two wheels, one being heated by a resistor close to the circumference. An endless belt of water-cooled steel or bronze is interposed between the film and the heater wheel to prevent sticking and rumpling of the film.

WEST GERMANY

The August 1960 issue of *Technische Mitteilungen Krupp* reviews the application of electrochemical probe surveys to revealing corrosion-sensitive zones in welds in 17% Cr steel. The Haber-Luggin capillary probe was held 0.004 in. above the polished surface of the welds. The voltage was developed in stirred 0.001 normal HCl, 90% alcoholic under nitrogen, with a calomel electrode for comparison. The heat-affected zone exhibited a low millivoltage tending toward a negative value, and indicating susceptibility. Heat treatment (2 hr. at 1290° F) or the addition of 0.64 Ti to the steel removed the negative or local anode regions in the HAZ.

Dilatometric Characteristics of Welded Steels

Quantitative measurements are reported for strain accompanying transformation and for the net strain imposed by a simulated welding thermal cycle

BY L. F. BUBBA, H. H. JOHNSON AND R. D. STOUT

Introduction

It is frequently pointed out that the weldability of structural steels is influenced by dimensional changes imposed by the welding thermal cycle upon the weldment. These strains control the localized stress system in the weldment. Thus they may thereby contribute to such problems as residual stresses, excessive distortion and cracking. These problems are particularly dangerous with steels of limited inherent ductility.

The strains and associated stresses in a weldment arise from several sources. Thermal stresses will develop in any material subjected to a nonuniform heating and cooling cycle i.e., thermal stresses exist only as a result of thermal gradients. The magnitude of a thermal stress is controlled by the thermal expansion coefficient of the material and the severity of the thermal gradient. Thermal stresses may be severe enough to induce plastic deformation in the steel, resulting in residual stresses and perhaps altered properties in the steel.

Transformation stresses are developed only in those materials which exhibit phase transformations when thermally cycled. With steels the austenite phase transforms upon cooling from welding to one or more of several transformation products, depending upon the cooling rate. Since all transformation products have a larger specific volume than austenite, an expansion strain always develops upon transformation. Substantial stresses can therefore accompany transformation, since it never occurs instantaneously throughout the entire volume. The transformation stresses may well be critical if the steel derives its strength from martensite, which frequently forms in low temperature ranges where ductility is limited and the stresses cannot be readily alleviated by plastic deformation.

It thus appears that the stress system in a weldment is strongly influenced by the transformation and thermal strains in the steel and weld metal arising from the welding thermal cycle. This problem has received wide recognition recently. Commission IX of the International Institute of Welding approved a report which suggested that further investigation of the transformation characteristics of steels would enhance understanding of their welding behavior. This problem is also contained in the Welding Research Council list of topics submitted by industrial sources as important areas for research.

Previous research was concentrated primarily upon transformation characteristics, i.e., determining the transformation temperature and products as a function of cooling rate.[1-3] A competent review of this work and its application to the cold cracking problem has appeared recently.[4]

Apparently there have been no quantitative investigations of the strain aspect of the problem, i.e., measurements of the strain accompanying transformation under varying conditions or of the net strain imposed by a simulated welding thermal cycle. Such measurements are described here for a variety of materials and thermal cycles.

Materials and Procedure

In addition to a weld metal, a series of carbon and alloy steels was investigated. The designations and compositions are listed in Table 1.

The weld metal was taken from the center of a multiple-pass butt weld deposited in HY-80 plate. The A212 and 4140 steels were as-rolled, and the A302 was normalized. The T-1 and HY-80 steels were quenched from 1700 and 1610° F respectively; both steels were tempered at 1200° F. Dilatometer specimens prepared from these materials were 50 mm long and 3.2 mm in diameter.

Dimensional changes were recorded with a Leitz dilatometer suitably modified for rapid thermal cycles. Induction heating was used for rapid heating, and helium gas quenching was employed for rapid cooling. During heating the steel was protected from oxidation by argon. A mirror galvanometer was incorporated in the dilatometer to provide direct temperature measurement for the dilatometer curve. The thermal cycle was followed with an X-Y recorder; the Y-axis recorded temperature from a thermocouple spark welded to a specimen, and the X-axis measured time from an electrical sweep circuit. A schematic outline of the apparatus

Table 1—Chemical Compositions, %, of Materials Investigated

Material	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	V	B
A212, Grade B	0.28	0.70	0.010	0.021	0.24	..	..	..	..	..	..
A302 Grade B	0.20	1.32	0.022	0.030	0.25	..	..	0.42	..	..	..
T-1	0.15	0.93	0.015	0.022	0.27	0.89	0.48	0.44	..	0.06	0.0031
AISI 4140	0.39	0.76	0.015	0.019	0.23	..	0.94	0.18	..	..	..
HY-80	0.16	0.31	0.016	0.0305	0.20	2.86	1.37	0.21	0.18	..	..
E11018 Weld Metal	0.09	1.40	0.02	0.025	0.49	1.30	0.07	0.35	0.10	..	..

L. F. BUBBA is associated with Wright Dev. Center, H. H. JOHNSON with Cornell Univ., and R. D. STOUT with Lehigh University.

Progress report on an investigation for the Weldability Committee of the Welding Research Council.

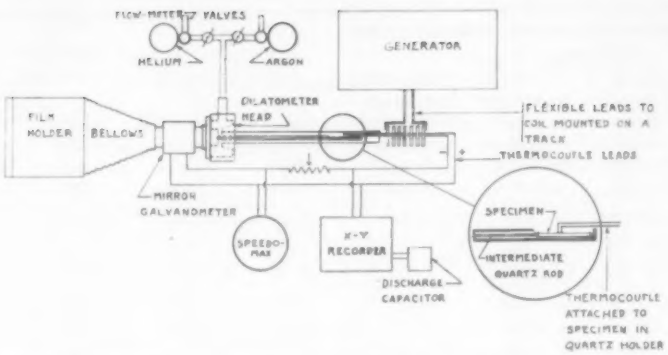

Fig. 1—Experimental arrangement of high speed dilatometer

is shown in Fig. 1.

Verification of the response of the high-speed apparatus is indicated by a comparison of low and maximum speed dilatometric curves for electrolytic copper—Fig. 2. The curves nearly superimpose, and the curve slopes are reasonably consistent with accepted values of the thermal expansion coefficient. Since copper is not ferromagnetic, it heats more slowly than steel for equivalent power inputs. Further verification was obtained on samples of pure nickel and of titanium.

To simulate welding conditions, the highest possible heating rate is desirable. With maximum power ferritic steels could be heated to the A_1 temperature in 1.5 sec. At this high heating rate, however, anomalous features were observed in the dilatometric curves. To obtain satisfactory and reproducible results with steel, it was necessary to heat initially at a lowered rate such that the A_1 temperature was attained in about five seconds, and then full power could be applied.

To provide a wide range of thermal conditions three peak temperatures and three cooling rates were utilized, yielding a total of nine thermal cycles for each material. The thermal conditions are listed in Table 2.

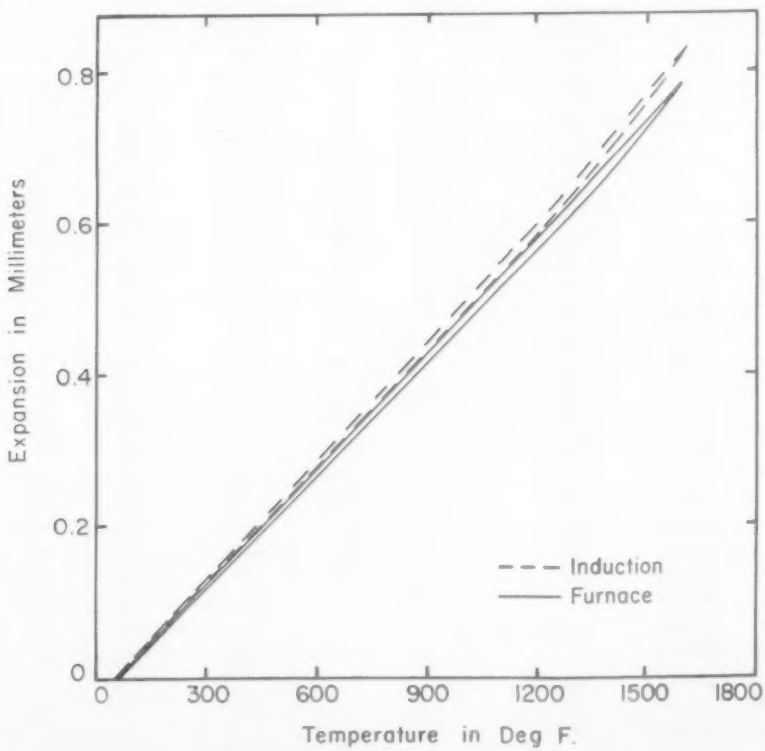

Fig. 2—Comparison of dilation curves of electrolytic copper when heated by a resistance furnace and by high frequency induction

Table 2—Thermal Cycles

Average peak temperature, °F	Average time to peak temperature, sec	Cycle no.	Average cooling rate at 1300° F, °F/sec
1625	8.5	1, 2, 3	135, 60, 30
2035	16	4, 5, 6	135, 60, 30
2375	21	7, 8, 9	135, 60, 30

Additional information obtained included the microstructure of each material in the as-received condition and after each thermal cycle. Vickers hardness readings were also taken.

Results

A schematic dilatometric curve is presented in Fig. 3 to define the transformation strain and temperature parameters in terms of which the data are presented and discussed. For steels and thermal cycles in which transformation occurs in a single temperature range, these parameters are descriptive of the transformation behavior. However, in those instances where transformation occurs in two separate temperature ranges, the parameters are less adequate. The parameters and hardness values are summarized in Table 3; the microstructural observations are in Table 4.

Continuous cooling transformation diagrams were constructed for the different materials, Figs. 4–6. Temperatures at the beginning and end of transformation were taken as the "change-of-slope" points on the dilatometric curves; times corresponding to these temperatures

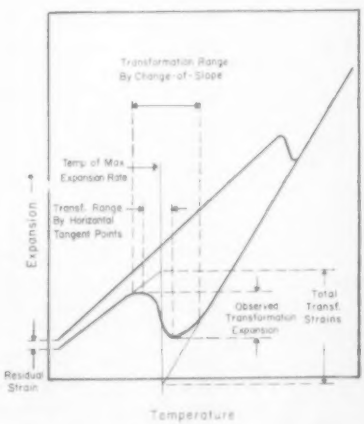

Fig. 3—Definitions of significant features in a high speed dilatometry curve of a structural steel. Data of Table 3 were obtained in accordance with these definitions

Table 3—Dilatometric Data on Selected Steels Subjected to Various Thermal Cycles

Steel	Peak temperature, °F	Cooling rate at 1300° F in °F/sec		Transformation temperature, °F on cooling: Change of slope temperature	Horizontal tangent temperature	Maximum rate expansion temperature	Strain measurements (Fig. 3), %: Observed transformation strain tension	Total transformation strain tension	Residual strain comparison	Original hardness, VHN	Final hardness, VHN
E11018 Weld Metal	1630	126	1	1060–600	935–800	875[a]	0.13	0.49	0.04	287	281
	1685	49.5	2	1110–790?	1010–880	960	0.22	0.43	0.02	287	262
	1650	32.6	3	1115–790	1035–885	980	0.22	0.45	0.05	287	240
	2045	130	4	1100–560	915–780	850[b]	0.13	0.52	0.08	287	297
	2025	45.8	5	1060–770	985–875	940	0.25	0.46	0.04	287	262
	2050	26.7	6	1060–750	1005–875	970	0.26	0.465	0.03	287	235
	2370	136.7	7	860–535	800–590	800[b]	0.200	0.47	0.04	287	322
	2380	56.5	8	1050–775	960–840	910	0.21	0.43	0.08	287	282
	2385	25.3	9	1070–770	980–960	950	0.26	0.465	0.06	287	246
A-212 Grade B	1635	168	1	1170–1030	1130–1035	1100	0.15	0.295	0	168	195
	1625	48	2	1230–1070	1175–1070	1150	0.16	0.33	0	168	183
	1610	35	3	1310–1130	1260–1120	1245	0.145	0.345	0	168	179
	2060	180	4	970–920	940–930	950	0.31	0.37	0	168	209
	2020	57	5	1220–1100	1140–1100	1130	0.26	0.375	0	168	196
	2050	31	6	1260–1130	1175–1130	1170	0.23	0.375	0	168	181
	2390	131	7	1025–850	955–860	920[b]	0.11	0.3	0.03	168	258
	2385	46.5	8	1180–1080	1100–1080	1100	0.27	0.37	0.02	168	203
	2425	22	9	1210–1130	1155–1130	1150	0.265	0.44	0.02	168	197
A302 Grade B	1610	168	1	855–450	715–625	570[a]	0.13	0.45	0.04	187	369
	1610	63	2	1020–635	960–860	930[a]	0.13	0.295	0.088	187	300
	1605	36	3	1090–790	985–880	950	0.16	0.4	0.12	187	266
	2035	118	4	710–500	675–560	650	0.335	0.485	0.02	187	437
	2050	55	5	1000–625	865–760	810	0.225	0.49	0.02	187	341
	2080	24	6	1030–800	940–850	900	0.27	0.445	0.059	187	271
	2330	123	7	680–520	640–535	625	0.36	0.485	0.069	187	427
	2370	55	8	950–660	860–770	820	0.285	0.5	0.059	187	333
	2370	30	9	990–790	915–840	890	0.3	0.43	0.07	187	267
T-1	1635	163	1	700–575	660–590	620	0.32	0.435	0.055	297	375
	1610	76	2	940–575	770–690	735	0.300	0.52	0.05	297	357
	1630	33	3	1035–680	870–785	850	0.24	0.49	0.06	297	302
	1985	166	4	760–530	720–610	700	0.3	0.475	0.08	297	390
	2010	60	5	840–600	770–710	740	0.4	0.545	0.08	297	379
	2035	32	6	830–690	805–780	800	0.41	0.525	0.08	297	327
	2400	122	7	720–515	700–575	680	0.325	0.485	0.08	297	419
	2350	54	8	860–600	775–705	755	0.36	0.525	0.05	297	410
	2365	19	9	900–675	860–800	845	0.36	0.5	0.08	297	312
HY-80	1650	128	1	850–580	750–615	680	0.16	0.42	0.09	221	339
	1625	66	2	950–580	840–680	785	0.14	0.43	0.10	221	322
	1610	25	3	950–560	875–725	830	0.13	0.39	0.17	221	295
	2050	170.5	4	815–480	565–480	570	0.37	0.525	0.02	221	405
	2010	48	5	950–560	860–680	790	0.215	0.51	0.01	221	390
	2030	31.5	6	950–560	865–720	830	0.21	0.475	0.02	221	317
	2360	158	7	670–450	665–500	640	0.325	0.495	0.04	221	408
	2400	54	8	820–500	745–610	700	0.35	0.545	0.04	221	383
	2375	23.5	9	910–650	870–780	855	0.3	0.5	0.04	221	310
4140	1605	112.5	1	650–450?	600–470	565	0.265	0.45	0.03[b]	292	383
	1610	82	2	610–380?	540–425	515	0.23	0.49	0	292	339
	1610	43	3	940–530	885–775	850[a]	0.09	0.33	0.07	292	369
	2015	138	4	620–410?	575–445	530	0.305	0.48	0.06[b]	292	548
	2020	61	5	630–385?	575–415	535	0.24	0.475	0.02[b]	292	503
	2060	27	6	920–570	865–815	850[a]	0.265	0.4	0.03	292	339
	2350	126	7	600–380?	560–410	520	0.26	0.46	0.01	292	536
	2370	54	8	770–400?	630–450	565	0.19	0.48	0.06	292	536
	2360	24	9	900–770	850–815	835	0.32	0.43	0.05	292	322

[a] Transformation in two temperature ranges (Split Transformation). [b] Tensile residual strain.

Table 4—Microstructural Analysis

Microconstituents Observed in Dilatometric Specimens after Experimental Runs

Steel	Run	Structure
E11018	1	Bainite (some ferrite?)
	2	Bainite + ferrite
	3	Ferrite + bainite
	4	Bainite (some ferrite), martensite
	5	Bainite + ferrite
	6	Ferrite + bainite
	7	Bainite + martensite
	8	Bainite + ferrite (acicular)
	9	Ferrite + bainite
A212	1	Fine pearlite and ferrite
	2	Pearlite + ferrite
	3	Lamellar pearlite + ferrite
	4	Pearlite + ferrite
	5	Pearlite + ferrite
	6	Pearlite + ferrite
	7	Pearlite, ferrite, martensite
	8	Pearlite and ferrite
	9	Acicular ferrite and pearlite
HY-80	1	Martensite
	2	Bainite
	3	Bainite
	4	Martensite
	5	Martensite + bainite
	6	Bainite
	7	Martensite
	8	Martensite (bainite?)
	9	Acicular bainite (martensite?)
Steel	Run	Structure
A302	1	Some martensite, bainite
	2	Ferrite + pearlite (bainite?)
	3	Fine ferrite + pearlite
	4	Martensite
	5	Bainite, ferrite (martensite?)
	6	Bainite
	7	Martensite
	8	Martensite + bainite
	9	Bainite
T-1	1	Martensite + bainite
	2	Bainite
	3	Bainite
	4	Martensite (bainite?)
	5	Bainite, some martensite
	6	Bainite
	7	Martensite
	8	Martensite, some bainite
	9	Bainite
4140	1	Martensite
	2	Martensite + bainite
	3	Bainite
	4	Martensite
	5	Martensite
	6	Bainite (15–20% martensite)
	7	Martensite
	8	Martensite
	9	Bainite (10–15% martensite)

were taken from the thermal analysis curves. Time was measured from the beginning of quenching. No great accuracy can be claimed for this procedure, but a satisfactory relative comparison of the different materials is evident.

The diagrams do indicate clearly the influence of austenitizing temperature upon the transformation behavior. Because of the rapid heating and cooling, the time at the lower peak temperature was insufficient to homogenize the austenite; this is reflected in accelerated transformation behavior upon cooling. With the high peak temperature appreciable grain growth was evident, and this delayed subsequent transformation.

E11018 Weld Metal

This material exhibited split transformation for all three peak temperatures when the maximum cooling rate was imposed—Table 3. The resulting microstructures contained varying amounts of martensite, bainite and ferrite. The martensite reaction always commenced at about 680° F and was therefore well separated in temperature from the bainite reaction. Both dilatometric and hardness data indicate that the maximum amount of martensite was associated with the highest peak temperature, probably because grain growth and austenite homogeneity hindered the nonmartensitic reactions. The influence of incomplete austenitization at the low peak temperature and of grain growth at the high temperature is evident in Fig. 4A.

For the intermediate and slow cooling rates, transformation occurred at approximately the same temperature range for all peak temperatures. This was in reasonable accord with microstructural and hardness observations, which indicated only some increase in primary ferrite at lower cooling rates. In accord with the transformation similarity, the transformation strains were nearly constant for these cycles, while the residual strains showed a trend to higher values with the high peak temperature.

A212—Grade B

As would be expected, austenite transformation occurred at higher temperatures in A212 steel than in the other materials. The predominant constituents were fine pearlite with increasing amounts of acicular ferrite at decreased cooling rates. The hardness data corroborate these observations.

With one thermal cycle, the maximum cooling rate and peak temperature, a split transformation was evident from the hardness, metallographic and dilatometric data. A martensite reaction occurred at 630° F in addition to the pearlite reaction at about 920° F, illustrating again the potent influence of large grain size in suppressing the decomposition of austenite to nonmartensitic products. The transformation behavior of A212 is summarized in Fig. 4B.

The observed transformation strains listed in Table 2 are reasonably constant for the two higher peak temperatures; the low value for cycle 7 merely reflects the in-

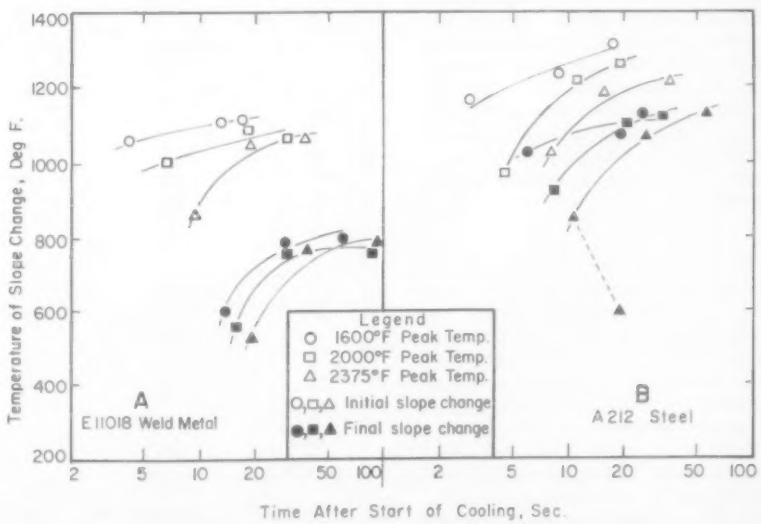

Fig. 4—Continuous cooling transformations in E11018 weld metal (A) and A212 steel (B) as detected from dilatometry curves

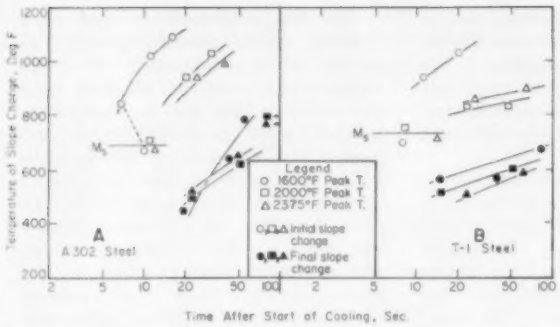

Fig. 5—Continuous cooling transformations in A302 (A) and T-1 (B) steels as detected from dilatometry curves

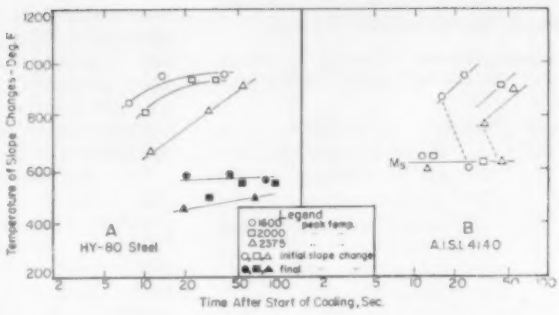

Fig. 6—Continuous cooling transformations in HY-80 (A) and A151 4140 (B) steels as detected from dilatometry curves

complete pearlite reaction. Significantly lower transformation strains are associated with the low peak temperature. For six of the nine thermal cycles, no residual strain was observed; this is in contrast to the behavior of the other materials. Perhaps residual strain is associated with alloy content in some unknown manner.

A302—Grade B

This Mn-Mo alloy steel exhibited austenite transformation over a greater temperature range, considering all thermal cycles, than any of the other materials. Split transformations were observed for cycles 1 and 2; with Cycle 1 the martensite and bainite reactions overlap just slightly in temperature, and with Cycle 2 the martensite and pearlite reactions are substantially separated. The transformation characteristics are summarized in Fig. 5A.

Once again low transformation strains are associated with low peak temperatures, although for cycles 1 and 2 this may be explained by the split transformations. For other thermal cycles the transformation strain seems independent of whether the microstructure is predominantly martensitic or bainitic, but there is some trend to smaller strains with higher transformation temperatures. The residual strains are irregular.

T-1

The continuous cooling transformation characteristics of this low-alloy high-strength steel are presented in Fig. 5B. Bainite and martensite are the microconstituents observed in varying amounts for the different thermal cycles. For all peak temperatures the amount of bainite increased with decreasing cooling rate. From the dilatometric curves it was evident that T-1 typically transforms over a small temperature range and that the bainite and martensite reactions overlap in temperature. Once again the transformation and residual strains seem not to depend upon whether the microstructure is predominantly martensitic or bainitic.

HY-80

The behavior of HY-80 was rather similar to that of T-1 and is presented in Fig. 6A. Bainitic and/or martensitic microstructures were observed with all thermal cycles, but transformation occurred over a wider range of temperatures than with T-1. There is some trend to higher transformation strains at high peak temperatures but no evidence of a trend in the residual strain values.

AISI 4140

This was the highest carbon material investigated and therefore exhibited austenite transformation at the lowest temperatures. Martensitic structures were observed except for the slowest cooling rates where the structures ranged from all bainite to bainite with 10–15% martensite. The transformation characteristics are presented in Fig. 6B.

A unique feature of 4140 was that a net expansion accompanied some thermal cycles. From the dilatometric curves it was evident that this occurred mainly because of continuing martensite formation and partly because the thermal expansion coefficient of martensite upon cooling was less than the thermal expansion coefficient of the as-received structure upon heating. Thus, the heating and cooling curves converged at low temperatures and occasionally crossed to give a net

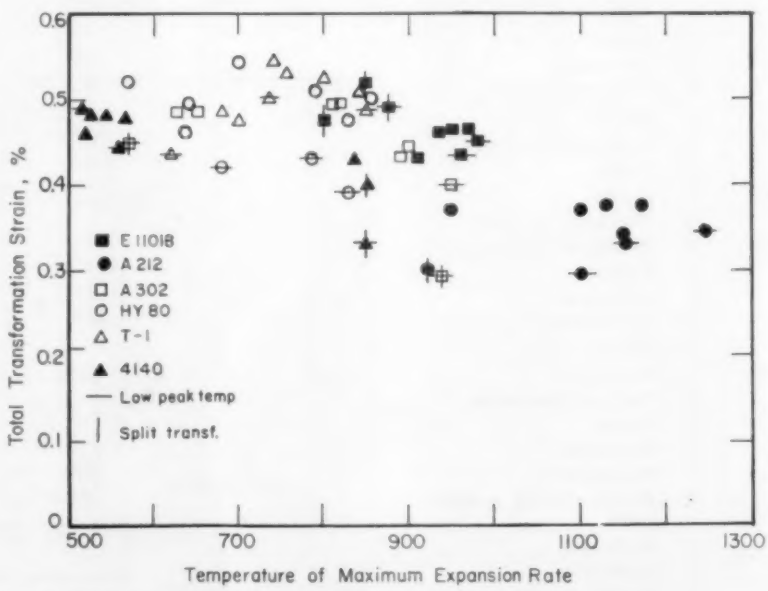

Fig. 7—Relation of the temperature at which phase transformation is most rapid to the expansion strain observed

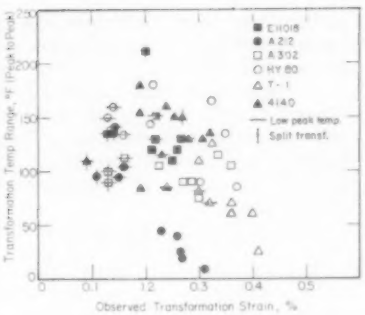

Fig. 8—Relation between the expansion during transformation to the range over which transformation occurs

expansion. This behavior was not observed with any other material, for their heating and cooling curves (after transformation) were invariably parallel.

It was also interesting to note that the transformation strains were no higher with 4140 than any other material. Apparently the strains associated with the martensite reaction are independent of carbon content.

Discussion

Considering the data for all materials, some interesting correlations among the transformation parameters may be developed. One of these is presented in Fig. 7 as a plot of total transformation strain vs. the temperature at which maximum expansion rate was observed. The scatter is reduced considerably if the data representing low peak temperatures and/or split transformation are disregarded. The total transformation strain is rather insensitive to transformation temperature up to about 800° F and thereafter decreases at a substantial rate. *The total transformation strain is insensitive to carbon content for all of the austenite decomposition products.* There is some indication of a transformation strain peak abound 700° F from the points for HY-80 and T-1, but the data are insufficient to prove or disprove the point.

Figure 7 also summarizes the temperature ranges over which the various steels transform. The 4140 and A212 steels transform at the lowest and highest temperatures respectively; the low-alloy steel data are scattered about the intermediate temperatures, with the low-carbon weld metal tending to higher temperatures.

Another interesting correlation involves the observed transformation strains and the temperature ranges of transformation—Fig. 8. In general, the observed transformation strain decreases as the transformation temperature range increases. This is as might be expected, since normal thermal contraction tends to counteract the transformation strain if the transformation temperature range is broad. The scatter in Fig. 8 is substantial, but the correlation is usually improved if individual materials are considered. This is particularly true for A212 and T-1 but somewhat less so for the other materials, especially 4140.

The quantitative interpretation of these results in terms of weldment behavior is difficult. In practice the transformation strains are superimposed upon a complex strain pattern controlled by the thermal cycle and joint geometry and restraint. Furthermore, transformation will not occur in all regions of the weldment at the same time. Some indication of this is presented in Figs. 9 and 10, which are plots for A212 and HY-80, respectively, of strain vs. time for thermal cycles of identical cooling rate but variable peak temperatures. Time was measured from the beginging of quenching. There is a strong trend for longer transformation times with high peak temperatures; this is abundant proof that the time for transformation at a given point in a weldment will depend upon the thermal cycle at that point. It would be interesting to determine such curves for actual thermal cycles in a typical weldment.

Idealized calculations suggest that transformation strains may be accompanied by substantial stresses. As an example, consider HY-80 subjected to thermal Cycle 8, where the observed transformation strain is 0.35%. For simplicity in calculation it may be assumed that the transformation is restrained by nontransforming surrounding material and that a linear stress system is developed. The simple form of Hooke's law may then be applied with a suitable temperature correction for the modulus of elasticity—a transformation stress of the order of 90,000 psi is obtained. This is substantially in excess of the yield strength of HY-80 at the transformation temperature and suggests that plastic deformation of the surrounding volume may accompany transformation. Similar results are obtained with other materials and thermal cycles.

The most dangerous situation with respect to transformation stresses will probably arise when split transformations occur with austenite transforming to pearlite and/or bainite at elevated temperatures and to martensite at lower temperatures. In this case martensite will be forming in a relatively hard matrix, and volume stresses must be considered. Assuming that the measured linear

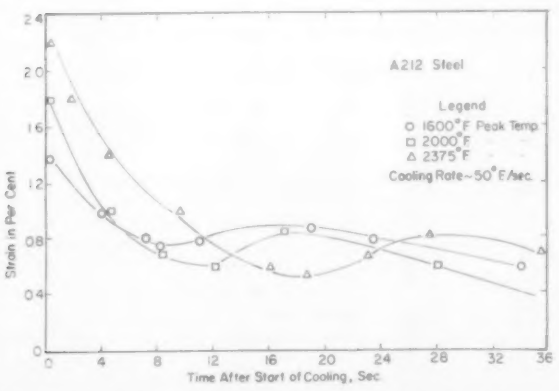

Fig. 9—Comparison of the size changes occurring in A212 steel when cooled from several peak temperatures typical of weld heat-affected zones

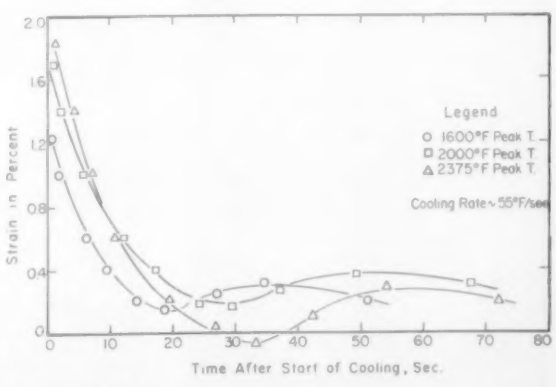

Fig. 10—Comparison of the size changes occurring in HY-80 steel when cooled from several peak temperatures typical of weld heat-affected zones

transformation strain is a principal strain, then the volume strain will be approximately three times the observed transformation strain. The volume stresses may then be calculated from Hooke's law relating volume stresses and strains with a temperature correction for the bulk modulus. As an example, consider 4140 steel subjected to thermal Cycle 6, where a martensite reaction begins at about 580° F, although most of the austenite transforms to bainite at 850° F. The average linear transformation strain for purely martensitic reactions in 4140 is 0.26%; this implies a volume strain of approximately 0.75%. This corresponds to a localized volume hydrostatic stress of about 190,000 psi, which would certainly be dangerous in materials of limited inherent ductility.

The factors controlling residual strains are not evident from this investigation. They appear to be highest for low-alloy high-strength steels and a minimum for plain carbon steels, but there is no obvious explanation for this behavior. Strains of the order of 0.1% were observed, corresponding to a uniaxial stress at room temperature of approximately 30,000 psi. This seems substantial and suggests that further investigation of the residual strain phenomenon would be desirable.

Conclusions

The following conclusions have emerged from a high speed dilatometric investigation of the transformation strain and temperature behavior of structural steels subjected to simulated welding thermal cycles.

1. In general the transformation strain is independent of carbon content and microstructure. Exceptions are noted with low peak temperatures or when split transformations occur.

2. The transformation strain is independent of transformation temperature below 800° F, but decreases at higher transformation temperatures.

3. The observed transformation strain decreases when transformation occurs over a wide range of temperatures.

4. Approximate calculations indicate that substantial stresses may be developed during transformation, particularly with split transformations involving a low temperature martensite reaction.

5. Substantial residual strains are observed with alloy steels but not with a plain carbon steel. These strains may be accompanied by residual stresses of considerable magnitude.

Acknowledgment

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A Final Last Minute Reminder

AUTHORS . . . .

August 15, 1961, is the deadline when application forms and abstracts must be postmarked in order to receive consideration for presentation at the AWS 43rd Annual Meeting to be held in Cleveland, Ohio, April 9–13, 1962.

The application form was included as a detachable insert in the May issue of the WELDING JOURNAL. Additional copies of the application may be obtained by writing or telephoning to AWS headquarters. 33 W. 39th St., New York 18, N. Y.

Brittle Failure of Steel Stack

Following analysis, stack failure was not due to wind but is postulated to be caused by a low static stress applied to plate near a notch at a low temperature

BY M. ZAR AND M. H. GOEDJEN

ABSTRACT. A tall steel stack, 21 yr old, of all-welded mild steel construction collapsed in cold weather. The nature of the failure and an investigation of probable stress levels at the time indicate that brittle fracture occurred, caused by temperature stresses in the plate and the fact that the steel temperature was far below the transition temperature.

Introduction

During January in 1959, a Commonwealth Edison Co. stack (Unit 15 in Fig. 1) fell in subzero weather after 21 yr of almost continuous service. Strangely enough, this occurred just two weeks after it had been permanently retired.

The 14 ft. diameter and 220 ft. high, self-supported structure on the roof of the station involved was reputed to be (in technical literature of September 1937) the first large all-welded steel stack in the country. It consisted of 30 cylindrical rings of $^3/_8$, $^1/_2$ and $^5/_8$ in. thicknesses. Four inches of brick, laid in Portland cement mortar, formed a full height lining.

The failure was a classic example of brittle fracture. Observers, who visited the site before the debris was cleared, were impressed with the unusual pattern of the collapse—as though the huge cylinder had exploded from within. The shattered appearance of the pieces (Figs. 2 and 3) and the fact that all debris had fallen within a radius of approximately 60 ft. indicated that external lateral forces were not responsible. There was a relatively insignificant wind of 15 mph out of the northwest at the time of failure. Chevron marks, which generally point to the origin of failure, were in abundance. Some of these were traced but indicated no less than six general locations of fracture origin.

At the outset it was hoped that the origin of failure could be located by piecing the various fragments together on the ground as a gigantic jigsaw puzzle. This did not prove feasible, since the pieces had to be cut into rather small sections to facilitate lowering them to the ground. In lieu of this approach, physical locations of various pieces were determined by checking plate thickness, shop welds, ladder markings, known points of previous repairs and samplings. Thorough visual examinations were made, and with the aid of comparison photographs, some information was obtained.

The vertical welds, which were not full-penetration, had a 12 yr record of minor hairline cracking. As cracks in these seams were discovered during periodic inspections, they were chipped out and replaced with three-pass, full-penetration welds. Later hairline cracks, in 1954 and 1955, were drilled at their extremities to arrest propagation. In spite of this history of weld cracking, a careful examination of the broken stack pieces did not reveal any broken welds, thus establishing the fact that the welded joints did not fail first.

Fig. 1—Unit 15 stack before failure

Fig. 2—Unit 15 stack collapse (seen from slightly above)

Fig. 3—Unit 15 stack collapse (seen from below)

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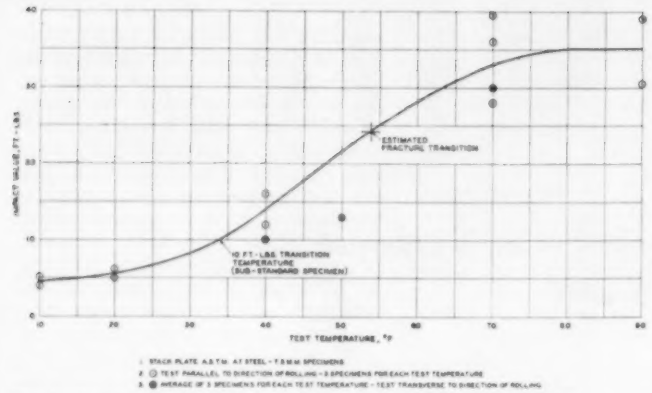

Fig. 4—Curve for Charpy V-notch impact values $^3/_8$-in. thick plate

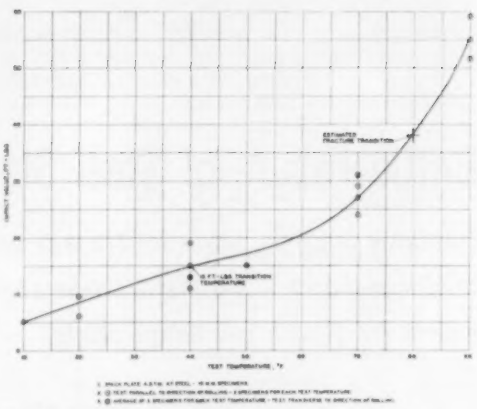

Fig. 5—Curve for Charpy V-notch impact values $^1/_2$-in. thick plate

Table 1—Spectrographic Chemical Analysis of Steel Plates

Sample	$^3/_8$ in. plate, %	$^1/_2$ in. plate, %	$^5/_8$ in. plate, %
Carbon	0.21	0.21	0.24
Manganese	0.45	0.46	0.37
Phosphorus	0.012	0.013	0.012
Sulfur	0.021	0.022	0.023
Silicon	0.10	0.10	0.10
Aluminum	0.03	0.05	0.02

NOTE: No other appreciable tramp element detected.

Table 2—Physical Tests of Steel

	$^3/_8$ in. plate	$^1/_2$ in. plate	$^5/_8$ in. plate
Yield point, psi	36,740	36,230	36,640
Tensile strength, psi	62,940	61,830	66,270
Elongation, %	28.4	31.2	26.5

Analysis

Laboratory testing of the Unit No. 15 stack materials and mathematical analysis of the stresses were needed to establish the existing conditions at failure. In brittle fracture research, which obtained its greatest impetus from World War II ship failures, it is generally agreed that three major criteria, which are explained in detail below, must be coincident to cause brittle failure—namely:

1. The steel must be below its transition temperature.
2. A notch must exist.
3. A stress above the critical stress level must be reached.

Transition Temperature

Impact Tests. Even though Charpy tests are not infallible for brittle determination, they are still the most universally accepted tests in connection with low temperature service. An examination of the Charpy curves (Figs. 4–6) reveals a scatter in the readings. Similar tests made previously on other Commonwealth Edison Co. stacks indicated an even greater pattern of irregularity. On all of these impact tests, the V-notch Charpy method was used, and the temperature at which the energy absorption was 15 ft-lb was designated as the transition temperature, the temperature below which a ductile steel appears to be brittle.

From each plate thickness of the collapsed stack, 15 samples were cut in the direction of rolling and 3 of these were broken for each of 5 selected temperatures to plot an average curve. Nine samples transverse to the direction of rolling were also cut for each plate thickness, and 3 of these were broken for each of 3 selected temperatures (Figs. 4–6). The results indicated a transition temperature in the neighborhood of +40° F.

Chemical Properties. The steel chemistry indicated a range not uncommon for ASTM A7 steel (Table

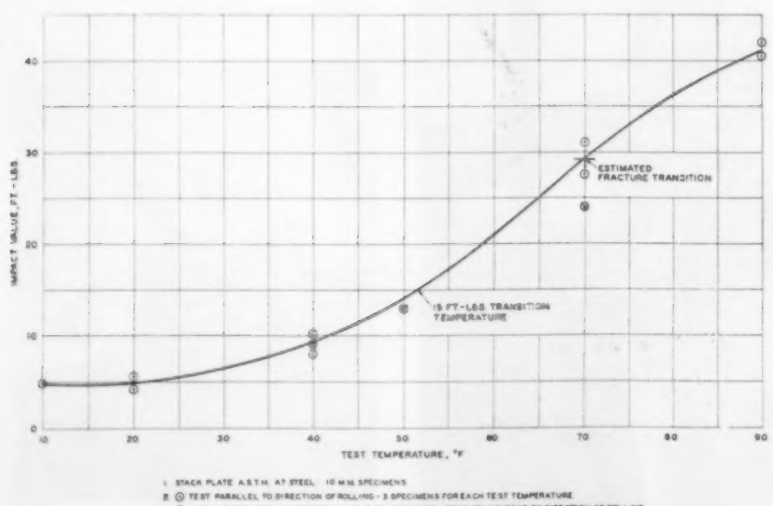

Fig. 6—Curve for Charpy V-notch impact values $^5/_8$-in. thick plate

Table 3—Review of Charpy Results of Various Commonwealth Edison Co. Steel Stacks

15 ft-lb assumed as establishing transition temperature

Stack	Steel type	Transition temperature, ° F
Fisk 15	A7	+33 to +51
Northwest 2	A7	+19 to +40
Ridgeland 5 & 6	A7	+42 to +70
Powerton 3 & 4	A7	−13 to +53
Will County 2	A131-B	−41 to −44
Will County 1	A131-B	−12 to −50
State Line 5	A131-B	−18 to +3
Crawford 7	A131-B	0 to −50
Joliet 6	A131-B	−8 to −50

1). This is especially true of the manganese-carbon ratio of about 2, which is generally conceded as too low to give good ductile properties. However, it should be emphasized that no limitation on these two elements is specified for A7 steel. The search for trace elements did not disclose anything unusual.

The presence of silicon and aluminum may indicate a definite attempt by the mill to deoxidize and refine this particular steel heat.

Physical Properties. The physical tests were also well within the limits specified for A7 steel (Table 2). Tests for yield point, tensile strength and elongation are not indicative of low temperature notch-toughness of steels. The yield point results correlate well with the carbon and manganese content of the samples.

Metallography. Metallographic examination of each material thickness in the area of a brittle failure revealed that all plates were above average in cleanliness and were free from inclusions and segregations. The grain structure would indicate that a relatively high roll finishing temperature was followed by a fast cooling to room temperature. The comparatively coarse grain size, particularly of the 1/2 and 5/8 in. plates, would be conducive to a high transition temperature (Figs. 7–11).

Evidence of extensive shattering can be observed in the 5/8 in. thick plate immediately behind, and following parallel with, the main fracture. This is of interest in that it may represent the shattering effect of the initial, very high, energy shock wave radiating out from the point of initial fracture.

Table 4—Wind and Dead Load Stresses

(a) Loads
Stack diameter: 13.9 ft
Pressure: Wind = 15 mph, $P = 0.002\ (15)^2 = 0.45$ psf
Lining weight: 5 in. brick = 60.0 psf = 5.0 lb per in. of circumference
Steel weight: 3.4 psi per ft of height, which allows for details and variations in plate thickness.

(b) Wind moments

5/8 in. plate: $M = \frac{(0.45 \times 13.9)\ \overline{219.75}^2}{2} = 150{,}800$ ft lb at base

1/2 in. plate: $M = \frac{(0.45 \times 13.9)\ \overline{180.64}^2}{2} = 101{,}500$ ft lb at 38 ft-1 1/4 in. above roof

(c) Dead Load Stresses

5/8 in. plate: $fs = \frac{P}{A} = 219.75\ \frac{(5.0 + 3.4)}{(0.625)} = 219.75\ (11.4) = 2500$ psi compression

1/2 in. plate: $fs = \frac{P}{A} = 180.64\ \frac{(5.0 + 3.4)}{(0.50)} = 180.64\ (13.4) = 2420$ psi compression

(d) Combined Stresses

I (steel plate only) $= \frac{\pi D^3 t}{8} = \frac{\pi(13.9)^3\ (1728)t}{8} = \frac{\pi(2685)\ (1728)t}{8} = 1{,}820{,}000$ in.^{4}

$C = \frac{13.9 \times 12}{2} = 83.5$ in.

5/8 in. plate:

$fs = \frac{P}{A} \pm \frac{Mc}{I} = 2500 \pm \frac{150{,}800(12)83.5}{1{,}820{,}000(0.625)} = 2500 \pm 133$ = 2633 psi max compression
= 2367 psi min compression

1/2 in. plate

$fs = \frac{P}{A} \pm \frac{Mc}{I} = 2420 \pm \frac{101{,}500(12)83.5}{1{,}820{,}000(0.500)} = 2420 \pm 112$ = 2532 psi max compression
= 2308 psi min compression

Table 5—Critical Wind Velocity and Thermal Stresses

Critical Wind Velocity

Based on the proportions of the steel stack, brick lining and building construction, calculations indicate that the natural resonant frequency of the system was 25.4 cpm, which coincides with a critical wind velocity of 21.8 mph.

The equivalent wind loading at resonance is 7.5 psf. For this loading, the bending stress in the 5/8 in. plate was 2220 psi, and the combined stress was 4720 psi maximum compression or 280 psi minimum compression.

Thermal Stresses

(a) Assumptions

Lining temperature at failure		+20° F
Steel temperature at failure		−10° F
Equilibrium temperature		+80° F
Coefficients of thermal expansion	Lining	3.2×10^{-6}
	Steel	6.5×10^{-6}
Modulus of Elasticity	Lining	5.0×10^6
	Steel	29.0×10^{-6}
Material thickness	Lining, in.	5
	Steel, in.	3/8, 1/2, 5/8

(b) Stresses

Based on the theory that the circumferential forces are in equilibrium, the tension in the steel plate equals the compression in the brick lining.

On this basis, stresses were calculated as follows:

3/8 in. plate: fs = 7950 psi tension
fb = 596 psi compression
1/2 in. plate: fs = 7420 psi tension
fb = 742 psi compression
5/8 in. plate: fs = 6600 psi tension
fb = 826 psi compression

Notches

In order to produce brittle failure at a stress level well below the ductile yield point, a sharp notch must be present. Where data are available on other structures, it appears that the great majority of brittle fractures originated at defects resulting from fabrication. Even though there is very little inclination for these failures to follow welded seams, welding (or other working of the material) has a tendency to initiate cracks because of flaws which provide the notch.[1] This is especially true in the case of incomplete fusion which existed in the vertical joints of this stack.

Stresses

The critical stress of a brittle steel is even more difficult to establish than its transition temperature. When a carbon steel is ductile, it will fail at roughly twice its yield stress. When it is nonelastic—that is, below its transition temperature—it will fail at a *fraction* of its yield stress. The lower the temperature, the less stress is required for fracture. The level of stress needed to cause failure at a given low temperature is the *critical* stress.[5]

It has been established by investigators of ship failures that the criti-

Fig. 7—Typical structure of $^3/_8$-in. thick plate immediately adjacent to brittle fracture face

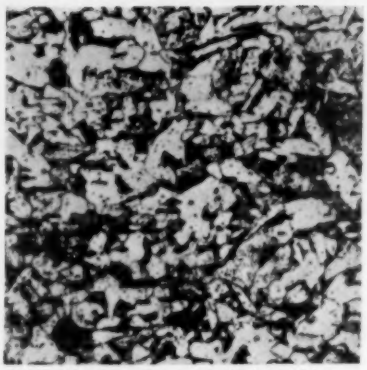

Fig. 8—Typical structure of $^1/_2$-in. thick plate immediately adjacent to brittle fracture face

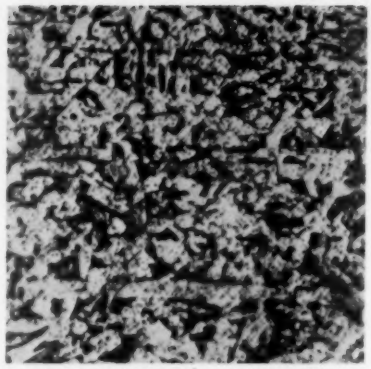

Fig. 9—Typical structure of $^1/_2$-in. thick plate immediately adjacent to fracture face showing some ductility

cal stress on broken vessel plates was about 8000 psi.[1] At Brown University, some unique experiments indicated failure as low as 12% of yield—about 4000 psi.[10] In Japan[1] and at the University of Illinois,[2] tests seem to prove that residual stresses have a marked effect on reducing the amount of applied stress needed to cause failure.

Since, at failure, the stack steel was at a temperature of approximately 50° F below its transition temperature, the level of critical stress must have been low. The residual stresses due to plate rolling,

Fig. 10—Typical structure of $^5/_8$-in. thick plate immediately adjacent to brittle fracture face

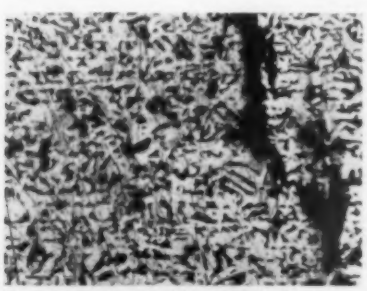

Fig. 11—Typical shatter crack in $^5/_8$-in. thick plate immediately behind and running parallel to main fracture face

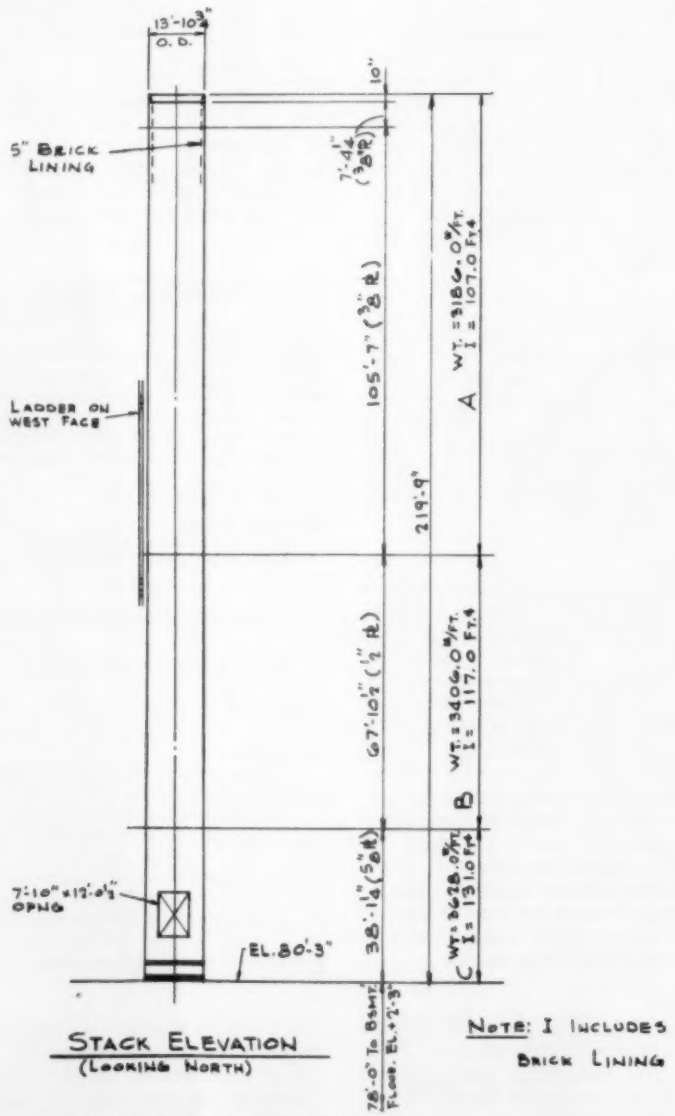

Fig. 12—Stack dimensions and properties

welding, etc., which existed in the plates, are, of course, impossible to establish. An attempt can be made however, to determine stresses resulting from other sources.

The most obvious stress producing force was the wind. Yet, for a wind velocity of 15 mph the plate stress due to wind was calculated to be less than 150 psi, tension or compression (Figs. 12–13 and Tables 4 and 5).

An investigation to determine the critical wind velocity of the stack was made. In a wind of critical velocity, the dynamic response of the stack produces far greater stresses than would be caused by winds of higher velocities, since at this velocity the stack goes into resonant vibration by periodic shedding of vortices.

By including the flexibility of the building supporting the stack, a critical wind velocity of 22 mph was established. In 1955, an inspector fortunately had the opportunity to measure and confirm the theoretical period of the movement on this stack in a strong wind. The observed period of two seconds coincides with a critical wind velocity of 24 mph.

Wind stresses can, therefore, be conclusively ruled out as a significant cause for failure, since the prevailing wind velocity of 15 mph was too low for either high dynamic stresses or for resonance. The pattern of the falling pieces around the stack base also bears this out. At this point it is of interest to note that a great majority of reported brittle failures apparently have taken place under conditions of static loading.[8]

The mortar was analyzed for the presence of calcium-sulfo-aluminate in order to determine whether there had been accumulated growth of the lining which could have induced a tensile stress in the steel shell of sufficient magnitude to cause failure. Only inconsequential traces of the compound were found. Apparently the stack operating temperature was too high to permit sufficient condensation and wetting of the lining to create significant amounts of calcium-sulfo-aluminate.

The most important stress source appears to be the restraint of the brick lining to the contraction of the steel plates. From the data of the weather bureau and the construction records, it was established that when the stack was lined in the summer of 1937 many of the daytime temperatures exceeded +80° F. Inasmuch as the shell and lining exerted no force on one another at the time of lining installation, there must have been, at the time of failure, tension stresses in the plates and compression in the brick, since the brick has a coefficient of expansion of about one-half that of the steel. The calculated tension stress in the steel due to the lining resisting the contraction of the shell is about 8000 psi at −10° F (Figs. 12–13 and Tables 4 and 5). This is a very nominal stress and could be resisted quite readily by a better quality steel.

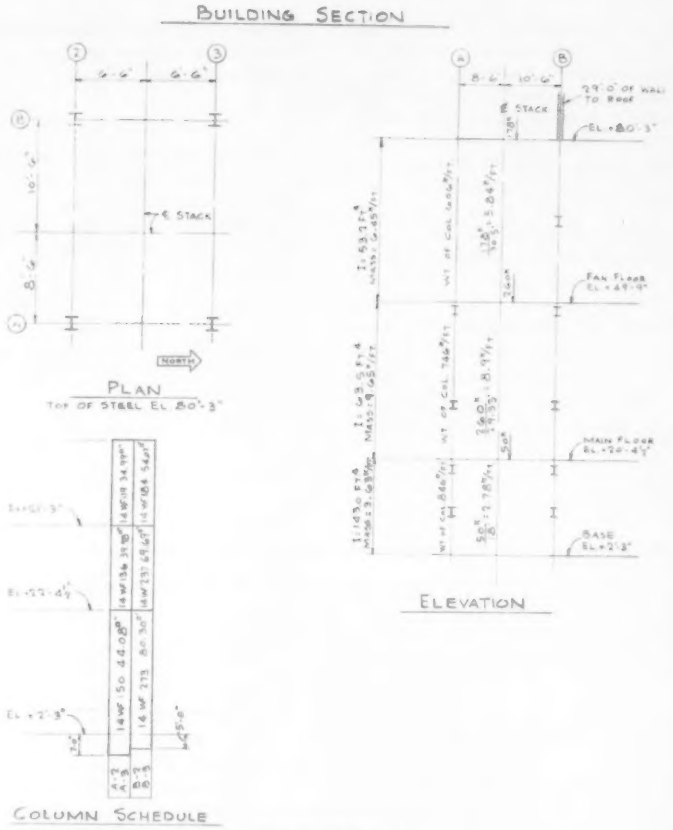

Fig. 13—Building dimensions and properties

Laboratory tests were performed at +75° F and −10° F on steel samples taken from the collapsed stack. Since these samples were free of residual stresses and notches, there were no significant differences in comparing the readings, at these two temperatures, for tensile strength, yield point or elongation.

Summary

Summarizing the above analysis, it appears that even a low static stress applied to a plate near a notch at low temperatures, where the plate has low notch toughness and may also contain residual stresses, can result in a failure such as was experienced here. It is the need for all these conditions to exist simultaneously that makes failures of this type uncommon.

It should be pointed out that propagation of a crack requires less severe stress conditions than those for fracture initiation. Cracks can propagate rapidly, even at low stress levels, as long as the steel is well below the transition temperature. This explains why the stack failed in an explosive manner.

Conclusions

1. Stacks built of high transition temperature steel should not have rigid linings which are in intimate contact with the steel. Some recent stacks have a mastic behind the brick.

2. Stacks of this type now in service should not be permitted to be off the line in zero weather. Experiments now being conducted by the Commonwealth Edison Co. indicate that a stack can be kept warm with light load on the boiler or by the use of gas or oil fired burners in the base of the stack, if the breeching dampers are kept closed.

3. In order to obtain control of carbon and manganese, a number of welded stacks in recent years have

been constructed of ASTM A131 Grade B steel, instead of the A7 steel previously specified. This, of course, is no guarantee against high transition temperatures, but Charpy tests taken on material from some of these stacks (Table 3) show a marked superiority over those made on the A7 steel. It is wise to obtain chemical, physical and Charpy tests on all stack material to establish the quality of steel purchased. A131 Grade C steel, which was unavailable for structures other than ships until rather recently, is now going into a few steel stacks. Since this steel is finer grained than Grade B, it should have better impact resistance at low temperatures and fortunately can be secured for only a slight increase in cost.

Acknowledgments

The calculations were prepared by J. J. Weider and the assembly of other material by A. M. Levy. Mr. Weider and Mr. Levy are engineers in the Structural Department of Sargent & Lundy.

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WRC Bulletin No. 70

Inert-Gas-Shielded Arc Welding of Ferrous Metals

Welding Research Council Bulletin No. 70, published in July 1961, contains the above interpretive report which was sponsored by the WRC Interpretive Reports Committee. The report reviews the use of TIG and MIG welding in the fabrication of ferrous metals. It has been prepared for the welding industry in the hope that it will provide members of the industry with a useful evaluation of these processes for welding steel. The report tells the story of the development of TIG and MIG welding, describes the physical characteristics of these processes, indicates the general area of their application to steel, compares in a general way the inert-gas metal-arc welding process to other welding processes, suggests to the reader the proper way of evaluating an economical TIG or MIG welding application, and looks into the immediate future to see how these inert-gas metal-arc processes will fare in competition with other methods.

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Effect of Welding Conditions on the Shrinkage Distortion in Welded Structures

Shrinkage distortion is analyzed from the standpoint of welding heat and external restraint effects

BY MASAKI WATANABE AND KUNIHIKO SATOH

SYNOPSIS. The problems of shrinkage distortion in welded structures are studied from two standpoints—namely, effect of welding heat and effect of external restraint. Shrinkage distortions in unrestrained welded joints are generally expressed by the following relation:

shrinkage distortion = (ξ_1 or δ) $\times F_g$

where ξ_1 and δ are inherent shrinkage and inherent angular change respectively, which relate to welding heat, and F_g is a function of geometrical shape of weldments. These functions are obtained for various welding conditions. Shrinkage distortion under external restraint is given by the following relation:

$$\begin{pmatrix}\text{shrinkage distortion under}\\ \text{external restraint}\end{pmatrix} = \begin{pmatrix}\text{shrinkage distortion in}\\ \text{unrestrained welded joint}\end{pmatrix} \times F_c$$

where F_c is a function depending on the degree of external restraint. The degrees of external restraint are obtained for various welded joints, from which the magnitude of the function F_c can be decided. At the end of this paper some examples of applications are shown.

Introduction

Shrinkage distortion in welding is one of the most troublesome problems in the construction of welded structures, but quantitative studies have never been made because it is affected by various factors. These factors may be divided into two groups as follows:

1. Factors relating to welding heat—(*a*) arc voltage, (*b*) welding current, (*c*) welding speed, (*d*) type and size of electrode, (*e*) welding method such as manual and automatic welding, (*f*) shape of groove in butt-welding, (*g*) size of fillet or weight of deposited metal, (*h*) number of passes, (*i*) weight of deposited metal removed by back chipping, etc.

2. Factors relating to external restraint—(*a*) welding sequence, (*b*) shape, size and arrangement of restraining members, etc.

In order to know fundamental characteristics about the effect of these various factors on the shrinkage distortion, a new approach has been made in this paper from the two standpoints—namely, effect of welding heat and effect of external restraint.

MASAKI WATANABE is Dr. Eng., Professor, and KUNIHIKO SATOH is Dr. Eng., Assistant Professor, Welding Engineering Dept., University of Osaka, Osaka, Japan.

Effect of Welding Heat

Parameters Relating to Welding Heat

As described above, factors relating to welding heat consist of nine or more factors. However, they will not always be independent because, for example, welding current will be necessarily increased and number of passes will be necessarily decreased with the use of larger size of electrode. In this paper, therefore, some parameters have been introduced which relate to these factors.

At first the case such that a straight bead is welded on a wide plate, thickness of which is h cm, was considered—Fig. 1. Shrinkage distortion in the plate will be most affected by the state of temperature rise in weld metal immediately after it is deposited; therefore, the temperature rise of weld metal was obtained at $x = -x_1$ (<0) cm in quasi-stationary state. If it is assumed that welding arc is a moving point heat source and thermal constants of the material are independent to temperature, then the average temperature rise θ in the section perpendicular to the plate surface at $x = -x_1$ is given by[1]

$$\theta = \frac{q}{2\pi\lambda h} \cdot e^{\frac{vx_1}{2k}} \cdot K_0\left(\frac{vx_1}{2k}\right) \quad (1)$$

where q is heat input per unit time (cal/sec), v is welding speed (cm/sec), λ is heat conductivity (cal/cm sec °C), k is temperature diffusivity (cm²/sec), and K_0 is modified Bessel function of the first kind. Equation 1 consists of term containing q and a function of $vx_1/2k$. Curve of the function vs. $vx_1/2k$ is approximately represented by a straight line on logarithmic diagram as shown in Fig. 2; if it is assumed that x_1/h is constant, the following relation will be obtained from the slope of the straight line:

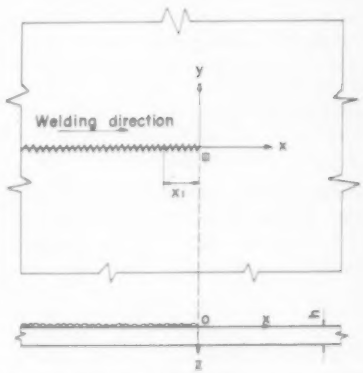


Fig. 1—Bead-on wide plate

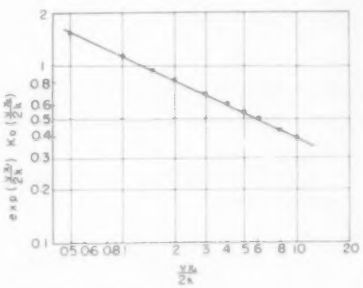


Fig. 2—Relation of exp. $\left(\frac{vx_1}{2k}\right) \cdot K_0\left(\frac{vx_1}{2k}\right)$ vs $\frac{vx_1}{2k}$

$$e^{\frac{vx}{2k}} \cdot K_0\left(\frac{vx_1}{2k}\right) \propto \left(\frac{vx_1}{2k}\right)^{-0.46} \propto (vh)^{-0.46} \cdot \left(\frac{x_1}{h}\right)^{-0.46} \propto (vh)^{-0.46} \doteqdot \frac{1}{\sqrt{vh}} \quad (2)$$

While heat input q is given by

$$q = 0.24\eta VI \quad (3)$$

where V is arc voltage, I is welding current and η is heat efficiency of welding arc. From eqs. 1, 2 and 3 the following relation is obtained;

$$\theta \propto \frac{\eta VI}{h\sqrt{vh}} \quad (4)$$

Equation 4 is for idealized point heat source, but the actual welding arc more or less has width. It was concluded in a previous paper[2] that the depth of fusion line in bead-on plates, which relates to the temperature rise, decreases with the increase of electrode size if the other conditions are definite, and the following relation was given:

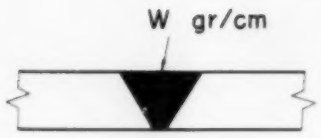
$$\text{depth of fusion line} \propto \phi^{-0.7} \quad (5)$$

where ϕ is the electrode size. From eqs. 4 and 5, θ is proportional to $\eta VI/\phi^{\alpha}h\sqrt{vh}$, where α is positive number less than 1. Therefore,

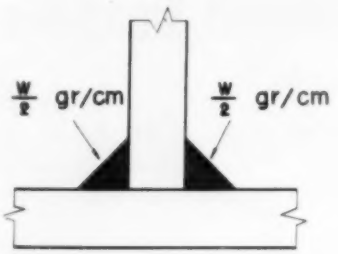
$$\frac{\eta VI}{\phi^{\alpha}\cdot\sqrt{v}} \equiv (Q) \quad (6)$$

may be adopted as a parameter relating to welding heat.

The above discussion is for bead welding. However, in actual welded joints—for example, in butt- and fillet-welded joints of given size as shown in Fig. 3—weld metal in the shaded area must be deposited to make a completed joint. In this case, shrinkage distortion will be affected by not only temperature rise in welding but also number of passes. Let weight of deposited metal per unit weld length necessary to make a completed joint be denoted by W and weight of deposited metal per unit weld length per welding of each pass be denoted by w_0. The necessary number of passes will then be given by



(a) Butt-welded joint



(b) Tee-fillet-welded joint

Fig. 3—(a) Butt-welded joint. (b) Tee-fillet-welded joint

$$\frac{W}{w_0} \equiv (N) \quad (7)$$

In this paper, N is adopted as another parameter relating to welding heat.

In butt-welding a double vee and double U groove, angular distortion will be largely affected by the ratio of weight of deposited metal in backing pass to the one in finishing pass. Therefore, the ratio W_A/W_B or W_A/W, where W_A and W_B are weight of deposited metal in backing and finishing pass respectively and W is total weight of deposited metal ($= W_A + W_B$), may be also considered to be a parameter relating to welding heat.

The relation between the three parameters Q, N and W_A/W and welding conditions relating to welding heat is shown in Table 1 by open circles. Table 1 being used, a systematic approach will be performed on the effect of various welding conditions on shrinkage distortion. For instance, if it is intended to investigate the effect of electrode size, successful results will be expected by examining on the effect of parameters Q and N.

Shrinkage Distortion Due to One-Pass Welding

In one-pass welding such as bead welding and one-pass fillet welding, it will be enough to consider only the parameter Q. In order to obtain the relation between shrinkage distortion and the parameter, a theoretical analysis has been performed on

Table 1—Relation between Parameters Relating to Welding Heat and Various Welding Conditions

Parameters relating to welding heat	Factors and notations	Welding conditions relating to welding heat: Arc voltage	Welding current	Welding speed	Type of electrode	Size of electrode	Manual or automatic welding	Shape of groove	Size of fillet weld	Numbers of pass	Deposited metal removed by back chipping
Temperature rise near the weld metal $Q=\frac{\eta VI}{\phi^{\alpha}\sqrt{v}}$	Welding current (I)		○		○	○	○				
	Welding speed (v)			○			○				
	Equivalent arc voltage*, (ηV)	○			○		○				
	Size of electrode (ϕ)					○					
Number of passes to make a complete joint $N=\frac{W}{w_0}=\frac{Wv}{\mu aI}$	Necessary weight of deposited metal (W)							○	○	○	○
	Welding current (I)		○		○	○	○				
	Welding speed (v)			○			○				
	Melted weight of rod per Amp. sec (a)				○	○	○				
	Deposition efficiency of rod (μ)				○		○				
	Wt. of deposited metal per each pass (w_0)		○	○	○	○	○				
Ratio of heat supplied in backing pass to the one in finishing pass, W_A/W_B								○			○

* η: Heat efficiency of welding arc, V: Arc voltage

bead-on wide plate as shown in Fig. 4 (a).

If it is assumed that inherent strains from which shrinkage distortion results remain in the region of breadth b near the weld line and small element $bhdx$ of the region is cut out from the plate, then the element by itself will contract in the neutral surface and bend concavely to welding side. The contraction or shrinkage and angular change due to bending in the direction transverse to weld line are represented by ξ_1 and δ ($\equiv \xi_1/h$), respectively, in Fig. 4 (b) and they are named inherent shrinkage and inherent angular change respectively. As for the inherent distortions the following assumptions were adopted: (1) inherent strains are produced in the region in which temperature during welding exceeds a critical value Θ_p above which material does not resist to deformation, (2) magnitude of longitudinal and transverse inherent strain is equal to each other and inherent shear strain is zero* and (3) inherent distortions are approximately represented by:

$$\left.\begin{aligned} \xi_1 &\propto \frac{1}{h}\int_0^h b_z dz \\ \delta &\propto -\frac{6}{h^3}\int_{-h/2}^{h/2} b_z z' dz' \end{aligned}\right\} \quad (8)\dagger$$

where b_z is breadth of Θ_p isotherms when it is most extended during welding at any point on weld line—Fig. 4 (c). Then the distribution of ξ_1 and δ is approximately uniform along weld line except for the ends of weld line in which temperature change is unstationary, and inherent distortions of the region are given as shown in Fig. 4.

Actual shrinkage distortion of the whole plate will be different from the inherent distortion, because the region in which no inherent strains exist resists to the inherent distortion. Actual shrinkage distortion is represented by:

$$\text{shrinkage distortion} = (\xi_1 \text{ or } \delta) \times F_g \quad (9)$$

where F_g is a function of geometrical shape of weldments. While ξ_1 and δ depend on welding heat, they are considered to be functions of parameter Q.

The relations of ξ_1 and δ vs Q were obtained by using eq. 8 and the results in the authors' previous paper.[2] The results are given by[4]

$$\left.\begin{aligned} \xi_1 &\propto \left(\frac{Q}{h}\right)^2 \\ \text{or} \quad \frac{\xi_1}{h} &= K_1 x^2 \end{aligned}\right\} \quad (10)$$

* Referring to the authors' previous report,[3] the assumptions 1 and 2 will be reasonable.

† See Appendix I.

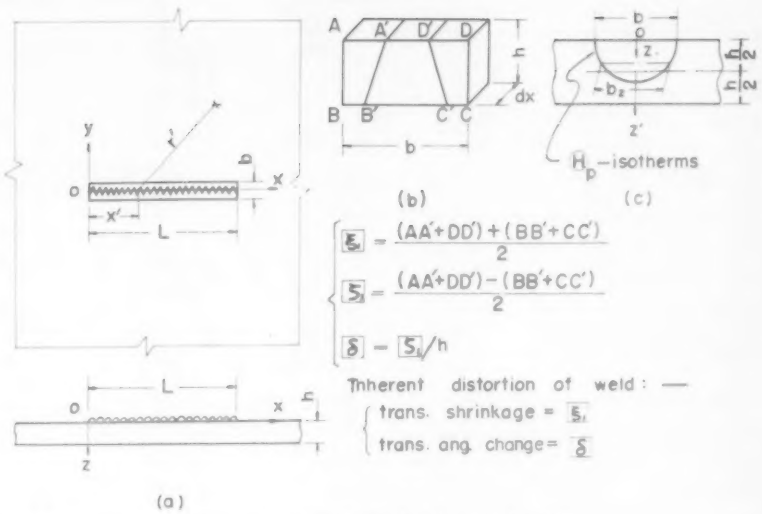


Fig. 4—Inherent shrinkage and inherent angular change of weld

$$\left.\begin{aligned} \delta &\propto (Qh^{-3/2})^{m+1}\cdot\exp.(-nQh^{-3/2}) \\ \text{or} \quad \delta &= K_2 x^{m+1}\exp.(-K_3 x) \end{aligned}\right\} \quad (11)$$

where $x \equiv 10^{-3} I/h\sqrt{vh}$ and K_1, K_2, K_3 and m are numerical factors.*

While, as known from eq. 9, F_g corresponds to shrinkage distortion of plate having unit inherent shrinkage and unit inherent angular change, and it can be obtained by using elastic theory. As an example, the function F_g of a rectangular plate as shown in Fig. 5 was obtained. The results are as follows: Transverse shrinkage for gage length B_g at mid-section A-A

$$F_g = 1 + \nu - \frac{\nu B_g}{B} - \frac{4}{\pi}\sum_{m=1,3,5}^{\infty}\frac{1}{m}(1+\nu)\frac{m\pi L}{B}\cdot\cosh\left(\frac{m\pi L}{B}\right) - (1-\nu)\sinh\left(\frac{m\pi L}{B}\right)\Big/\times\frac{1}{m}\sin\frac{m\pi B_g}{B}\Big/ \div m\left(\sinh\frac{2\pi L}{B}+\frac{2m\pi L}{B}\right) \quad (12)$$

Transverse angular change at mid-section A-A

$$F_g = 1 + \frac{\nu}{2} - \frac{8}{\pi^2}\sum_{m=1,3,5}^{\infty}\frac{1}{m}(1+\nu)\frac{m\pi L}{B}\cdot\cosh\left(\frac{m\pi L}{B}\right) - (1-\nu)\sinh\left(\frac{m\pi L}{B}\right)\Big/ \div m^2\left(\sinh\frac{2m\pi L}{B}+\frac{2m\pi L}{B}\right) \quad (13)$$

The magnitude of numerical factors in eqs. 10 and 11 was determined by analyzing some experimental results on transverse shrinkage for gage length 50 mm and angular change of 200 × 200 × 6–20 mm rectangular plates. Some examples are shown in Figs. 6 and 7, from which the magnitude of K_1, K_2 and K_3 can be determined. For instance, angular change for 4 mm ilumenite type electrode is given by:

$$\delta = 4.30x^{2.5}\exp.(-10.0x) \quad (14)$$

Putting $L/B = 1$ in eq. 13, it follows that:

$$F_g = 1.034 \quad (15)$$

Equations 14 and 15 being substituted in eq. 9, inherent angular change is given by:

$$\delta = \frac{\delta}{1.034} = 4.15x^{2.5}\exp.(-10.0x)$$

or

$$\delta = 0.131\times10^{-6}\left(\frac{I}{h\sqrt{vh}}\right)^{2.5}\exp.\left(-10.0\times10^{-3}\frac{I}{h\sqrt{vh}}\right) \quad (16)$$

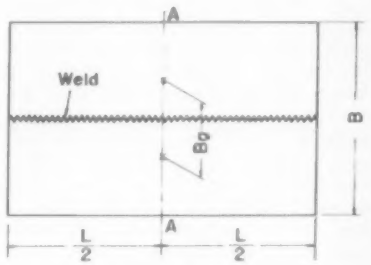


Fig. 5—Rectangular plate obtained as function of F_g

The same method as described above will be applied for the case of one-pass fillet welding, because it is not essentially different from bead welding. The results of one-pass fillet welding is in Fig. 8; in this case the analogous equation to eq. 11 can be obtained.[5]

* It may be considered that $\eta V/\phi\alpha$ is unchanged for the same type and size of electrode[3] and, therefore, the factor $\eta V/\phi\alpha$ is included in K_1, K_2 and K_3.

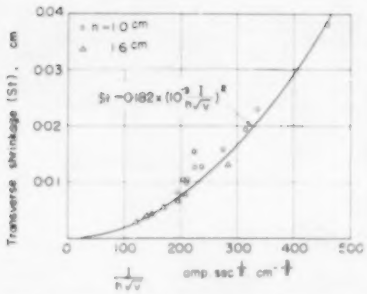


Fig. 6—Effect of welding conditions on the transverse shrinkage of bead-on plates. Electrode size 4 mm ϕ

Conventional formulas of ξ_1 and δ due to one-pass welding are summarized in Table 2 for various sizes of electrode.

Shrinkage Distortion Due to Multipass Welding

In multipass welding, shrinkage distortion depends on not only parameter Q but also parameter N. It can be certified in the measurements of angular change due to multipass fillet welding that if welding conditions are definite for each pass or Q is constant, then angular change is approximately proportional to number of passes—Fig. 9. Moreover, even in multipass welding, welding in each pass except for the first pass in butt welding will be considered to be essentially identical with bead welding. Assuming that the law of superposition is applied to shrinkage distortion in multipasss welding, inherent shrinkage distortion for multipass fillet and butt welding can be obtained from eqs. 10 and 11. The results are as follows:

1. Multipass fillet welding[5]

$$\delta \propto N\,(Qh^{-2/3})^{m+1} \exp.\ (-nQh^{-2/3}) \quad (17)$$

$$\delta \propto NQh^{-2/3} \qquad (\text{when } h \gtrsim 1 \text{ cm}) \quad (18)$$

2. Multipass butt welding[6]

$$\xi_1 - \xi_{1_0} \propto \left(\frac{Q}{h}\right)^2 N \log. N \quad (19)$$

$$\delta \propto Q^m N h^{-2} \left[2 \exp. \left\{ -nQh^{-2/3} \left(\frac{W}{W_A}\right)^{2/3} \right\} - \exp.(-nQh^{-2/3}) \right] \quad (20)$$

where ξ_{1_0} is inherent shrinkage due to welding of the first pass in butt-welded joints.

Conventional formulas of ξ_1 and δ due to multipass welding are summarized in Table 2.

Effect of External Restraint

Degree of External Restraint

In practical work on various structures, welding is performed more or less under external restraint. In this case shrinkage distortions in weld metal will be controlled at high temperature, and inherent shrinkage and inherent angular change will be smaller than in unrestrained welded joints.

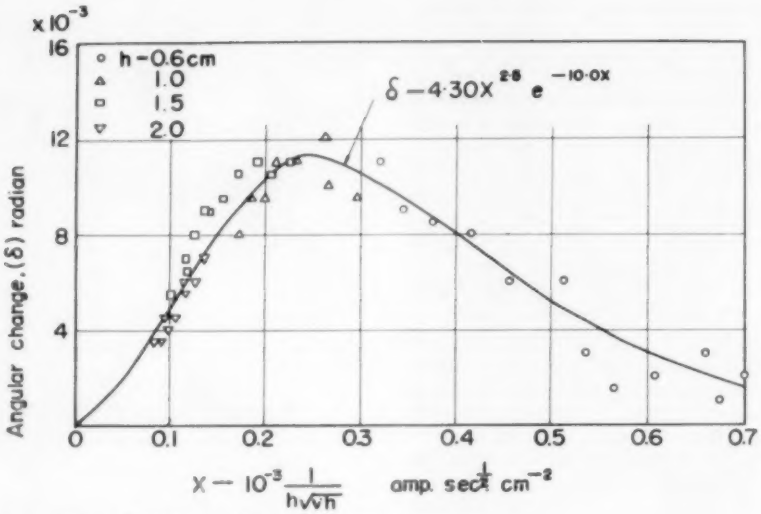


Fig. 7—Effect of welding conditions on the angular change of bead-on plates. Electrode size 4 mm ϕ

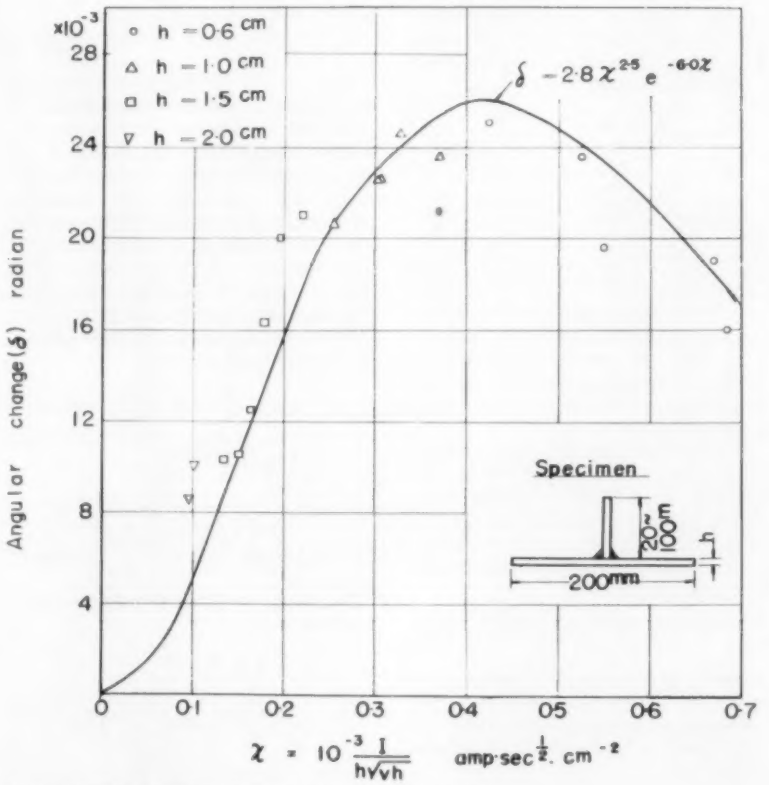


Fig. 8—Effect of welding conditions on the angular change of tee-fillet joint. Electrode size 4 mm ϕ

The authors' study proceeded under the idea that, if factors relating to welding heat are definite, the ratio of shrinkage distortion under external restraint to the one in unrestrained welded joint is uniquely decided by the degree of external restraint to which weld-

Table 2—Inherent Shrinkage and Inherent Angular Charge in Various Welded Joints

Joints	Type of Functions	Conventional Formulas	Physical Meaning of Constants	Examples of Conventional Formulas
Bead-on Plate	Inherent Shirinkage $\overline{\varepsilon_x} \propto \left(\frac{Q}{h}\right)^2$	$\overline{\varepsilon_x} = C\left(\frac{I}{h\sqrt{v}}\right)^2$ ···(1)	$C = \frac{\eta V}{\phi^{0.25}}\left(\frac{I}{h\sqrt{v}}\right)^2$	Ilumenite type 4mmϕ $\overline{\varepsilon_x} = 0.153\times10^{-4}\left(\frac{I}{h\sqrt{v}}\right)^2$ in cm Unionmelt rod 4mmϕ $\overline{\varepsilon_x} = 0.0240\times10^{-4}\left(\frac{I}{h\sqrt{v}}\right)^2$ in cm
	Inherent Angular Change $\overline{\delta} \propto (Qh^{-3/2})^{m+1}\exp(-nQh^{-3/2})$	$\overline{\delta} = C_1\left(\frac{I}{h\sqrt{vh}}\right)^{m+1}\times \exp\left\{-C_2\left(\frac{I}{h\sqrt{vh}}\right)\right\}$ ···(2)	$C_1 = \left(\frac{\eta V}{\phi^{0.25}}\right)^{2.5}$ $C_2 = \frac{\eta V}{\phi^{0.25}}$ $m = 1.5$	Ilumenite type 4mmϕ $\overline{\delta} = 0.131\times10^{-4}\left(\frac{I}{h\sqrt{vh}}\right)^{2.5}\exp\left(-10.0\times10^{-2}\frac{I}{h\sqrt{vh}}\right)$ in radian " 6mmϕ $\overline{\delta} = 0.105\times10^{-4}\left(\frac{I}{h\sqrt{vh}}\right)^{2.5}\exp\left(-9.14\times10^{-2}\frac{I}{h\sqrt{vh}}\right)$ in radian " 8mmϕ $\overline{\delta} = 0.0654\times10^{-4}\left(\frac{I}{h\sqrt{vh}}\right)^{2.5}\exp\left(-7.56\times10^{-2}\frac{I}{h\sqrt{vh}}\right)$ in radian Unionmelt rod 4mmϕ $\overline{\delta} = 0.0448\times10^{-4}\left(\frac{I}{h\sqrt{vh}}\right)^{2.5}\exp\left(-5.92\times10^{-2}\frac{I}{h\sqrt{vh}}\right)$ in radian
Tee-fillet Joint	Inherent Angular Change one pass: $\overline{\delta} = (Qh^{-3/2})^{m+1}\exp(-nQh^{-3/2})$ multi pass: $\overline{\delta} = N(Qh^{-3/2})^{m+1}\exp(-nQh^{-3/2})$ $\overline{\delta} = NQh^{-3/2}$ (when $h \gtrsim 1$cm)	$\overline{\delta} = C_1\left(\frac{I}{h\sqrt{vh}}\right)^{m+1}\times \exp\left\{-C_2\left(\frac{I}{h\sqrt{vh}}\right)\right\}$ ···(3) $\overline{\delta} = \frac{W}{w_0}C_1\left(\frac{I}{h\sqrt{vh}}\right)^{m+1}\times \exp\left\{-C_2\left(\frac{I}{h\sqrt{vh}}\right)\right\}$ ···(4) $\overline{\delta} = CWh^{-3/2}$ (when $h \gtrsim 1$cm) (5)	Ditto $C = \left(\frac{\eta V}{\mu a}\right)\left(\frac{\sqrt{v}}{\phi^{0.25}}\right)$	Ilumenite type 4mmϕ one pass $\overline{\delta} = 0.0885\times10^{-4}\left(\frac{I}{h\sqrt{vh}}\right)^{2.5}\exp\left(-6.00\times10^{-2}\frac{I}{h\sqrt{vh}}\right)$ in radian Ilumenite type 4mmϕ multi pass $\overline{\delta} = 10.5\times10^{-4}Wh^{-3/2}$ in radian
Butt Joint	Inherent Shrinkage $\overline{\varepsilon_x} - \overline{\varepsilon_x}_0 = \left(\frac{Q}{h}\right)^2 N\log_e N$ where $\overline{\varepsilon_x}_0$ is inherent shrinkage due to welding of first pass	$\overline{\varepsilon_x} = C_1\left(\frac{A}{h^2}\right)\log_e\left(\frac{W}{w_0}\right) + C_2\left(\frac{A}{h^2}\right)^{1/2}$ ···(6)	$C_1 = \left(\frac{\eta V}{\mu a}\right)\left(\frac{\eta VI}{a^{0.5}}\right)$ $C_2 = \sqrt{\frac{\eta V}{\mu a}}\sqrt{\frac{\eta VI}{v}}$ $w_0 = \mu aI/v$	Ilumenite type 3.2mmϕ $\overline{\varepsilon_x} = 0.0960\left(\frac{A}{h^2}\right)\log_e\left(\frac{W}{w_0}\right) + 0.0416\left(\frac{A}{h^2}\right)^{1/2}$ in cm " 4mmϕ $\overline{\varepsilon_x} = 0.1021\left(\frac{A}{h^2}\right)\log_e\left(\frac{W}{w_0}\right) + 0.0584\left(\frac{A}{h^2}\right)^{1/2}$ in cm " 5mmϕ $\overline{\varepsilon_x} = 0.1530\left(\frac{A}{h^2}\right)\log_e\left(\frac{W}{w_0}\right) + 0.0745\left(\frac{A}{h^2}\right)^{1/2}$ in cm " 6mmϕ $\overline{\varepsilon_x} = 0.1249\left(\frac{A}{h^2}\right)\log_e\left(\frac{W}{w_0}\right) + 0.0690\left(\frac{A}{h^2}\right)^{1/2}$ in cm
	Inherent Angular change $\overline{\delta} = \frac{Q^m N}{h^2}\left\{2\exp\left\{-nQh^{-3/2}\left(\frac{W}{W_A}\right)^{1/4}\right\} - \exp(-nQh^{-3/2})\right\}$	$\overline{\delta} = C_1\left(\frac{A}{h^2}\right)\left\{2\exp\left\{-C_2h^{-3/2}\left(\frac{W}{W_A}\right)^{1/4}\right\} - \exp\left(-C_2h^{-3/2}\right)\right\}$ ···(7)	$C_1 = \frac{1}{w_0}\left(\frac{\eta VI}{\phi^{0.25}\sqrt{v}}\right)^{0.5}$ $C_2 = \frac{\eta VI}{\phi^{0.25}\sqrt{v}}$	Ilumenite type 4mmϕ $\overline{\delta} = 0.221\left(\frac{A}{h^2}\right)\left\{2\exp\left\{-2.74h^{-3/2}\left(\frac{W}{W_A}\right)^{1/4}\right\} - \exp\left\{-2.74h^{-3/2}\right\}\right\}$ " 6mmϕ $\overline{\delta} = 0.221\left(\frac{A}{h^2}\right)\left\{2\exp\left\{-4.34h^{-3/2}\left(\frac{W}{W_A}\right)^{1/4}\right\} - \exp\left\{-4.34h^{-3/2}\right\}\right\}$ " 8mmϕ $\overline{\delta} = 0.164\left(\frac{A}{h^2}\right)\left\{2\exp\left\{-4.70h^{-3/2}\left(\frac{W}{W_A}\right)^{1/4}\right\} - \exp\left\{-4.70h^{-3/2}\right\}\right\}$
Notations	I: (Welding current in A) v: (Welding Speed in cm/s) W: (Weight of deposited metal per unit weld length in gr/cm) $= 7.8(A + A')$ A: (Sectional area of groove of butt joint in cm^2) A': (Sectional area of groove due to back chipping in cm^2) w_0: (Weight of deposited metal per unit weld length per welding of each pass in gr/cm)	h: (Thickness of plate in cm) W_A: (Weight of metal deposited in backing pass in gr/cm) V: (Arc Voltage in V) η: (Heat efficiency of welding arc) μ: (Deposition efficiency of rod) a: (Melted weight of rod per unit current and unit time in gr/A. sec) ϕ: (Diameter of rod in mm)	(Note) In this table the magnitudes of C_1 and C_2 in eqs. (6) and (7) corresponding to the following welding conditions are shown. Size of electrode (mm): 3.2, 4, 5, 6, 8 Current (A): 120, 150, 210, 260, 340 Welding Speed (cm/s): 0.3, 0.3, 0.3, 0.3, 0.3	

ments are subjected—that is to say:

$$\begin{pmatrix}\text{shrinkage distortion under}\\ \text{external restraint}\end{pmatrix} = \begin{pmatrix}\text{shrinkage distortion in unrestrained}\\ \text{welded joint}\end{pmatrix} \times F_c \quad (21)$$

where F_c is a function depending on the degree of external restraint.

As for the degree of external restraint for transverse shrinkage of butt welded joints various definitions have been given for some restrained specimens.[7-9] In an analogous manner to them, restraint coefficient as a measure for the degree of external restraint was defined as follows:

> Restraint coefficient (p) for transverse shrinkage = average value of transverse stress along weld line necessary to produce average dislocation of 1 mm along the weld line.

The restraint coefficient can be obtained by using elastic theory. For the specimens shown in Fig. 10 it is given by the following equation:

1. H-type restrained specimen

$$p = \frac{E}{B}\cdot\frac{1}{1 + (L_c/2L_s)} \quad (22)$$

2. Circular-ring-type restrained specimen

$$p = \frac{E}{4\pi}\cdot\frac{1}{b-a}\left(\log_e\frac{b}{a} - \frac{b^2-a^2}{b^2+a^2}\right) \quad (23)$$

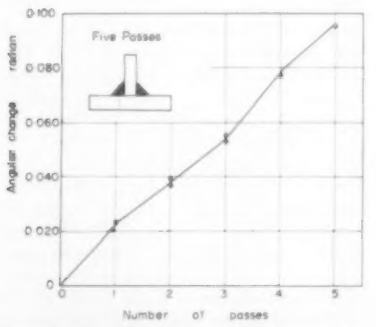
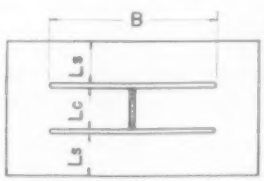


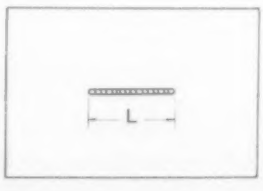
Fig. 9—Effect of number of passes on the angular change of a tee-fillet joint. Mother plate 200 × 100 × 10 mm and stiffener 100 × 50 × 10 mm



(a) H-type specimen

Fig. 10—Three types of restrained specimen

(b) Circular ring type specimen



(c) Slit type specimen

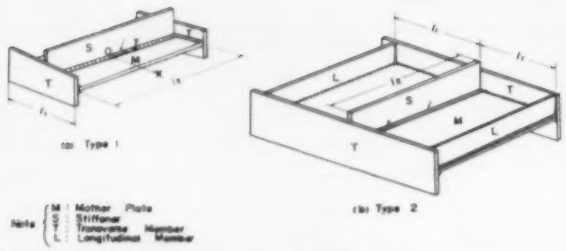


Fig. 11—Two types of tee-fillet restrained joint

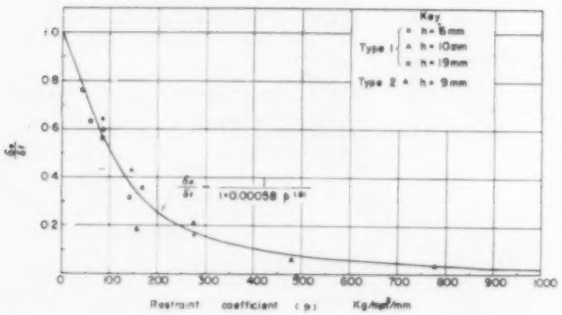


Fig. 12—Effect of external restraint on the transverse shrinkage of butt-welded joints

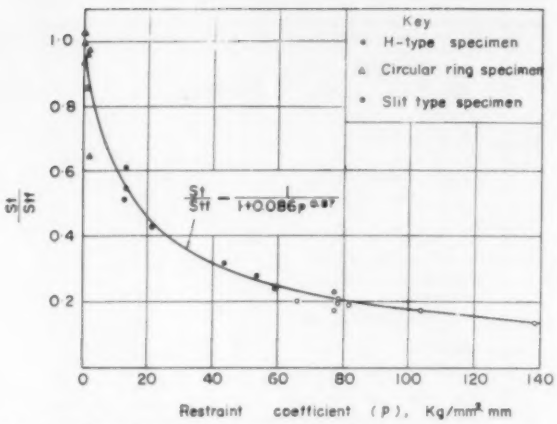


Fig. 13—Effect of external restraint on the angular change of tee-fillet welded joints

3. Slit-type restrained specimen

$$p = \frac{2E}{\pi L} \qquad (24)$$

In the same way restraint coefficient for angular change can be defined. As a substitute for dislocation and transverse stress in the neutral surface of the plate, dislocation at the surface of plate due to angular change and maximum bending stress was respectively used in the present case. Then the restraint coefficient is defined as follows:

Restraint coefficient (p) for angular change = average value of maximum bending stress along weld line necessary to produce average angular change of $1/h$ radian along the weld line, where h is plate thickness in millimeter.

For example, in the two types of tee-fillet joints as shown in Fig. 11, angular change of the joint shown by arrow is restrained by the transverse and longitudinal members. Restraint coefficient of the joints was determined by elastic energy method.[10] The results are as follows:*

Type 1

$$p = \frac{E}{1-\nu^2}\cdot\frac{\pi^2}{8l_2}\left\{\frac{\pi^2}{48}\left(\frac{l_1}{l_2}\right)^3 + \frac{(1-\nu)\pi^2}{2}\left(\frac{l_1}{l_2}\right)\right\} \qquad (25)$$

Type 2

$$p = \frac{E}{1-\nu^2}\cdot\frac{\pi^2}{8l_1}\left\{1.5 + 1.975\left(\frac{l_1}{l_2}\right)^2 + 0.927\left(\frac{l_1}{l_2}\right)^4\right\} \qquad (26)$$

Relation of Shrinkage Distortion Under External Restraint vs. Restraint Coefficient

In order to decide the function F_c in eq. 21, some experimental data of shrinkage distortion in various restrained specimens were analyzed by using restraint coefficient (p). At first the relation between average transverse shrinkage of three types of specimens shown in Fig. 10† and p presented by eqs. 22, 23 and 24 was investigated. Figure 12 shows the relation of the ratio of average transverse shrinkage (S_t) to the one in unrestrained welded joint (S_{tf})‡ versus p.

In the same way, the data of angular change in the specimens shown in Fig. 11 were analyzed. The results are shown in Fig. 13, where δ_0 is angular change at the center of weld line in restrained specimens, δ_f is angular change in unrestrained tee-fillet welded joints, and p is calculated from eqs. 25 and 26.

It may be said from Figs. 12 and 13 that these data are approximately represented by one curve despite the fact that various conditions are different from one to the other. It can be concluded, therefore, that the function F_c in eq. 21 or the ratio of shrinkage distortion under external restraint to the one in unrestrained welded joint is decided by p and it is independent of the other conditions.

Applications

As stated initially, shrinkage distortions in welded structures are affected by various factors. As described in this paper, however, the magnitude of shrinkage distortion may be predicted for given welding conditions and any solution may be given for problems on shrinkage distortions. Applications are described below under separate headings.

Prediction of the Magnitude of Shrinkage Due to Butt-Welding in Assemblies of Ship Construction

For this problem eq. 6 in Table 2 can be utilized because butt welding in practice will be done under very small external restraint. If weld length is very large and gage length measuring shrinkage is very small as compared with the width of the plate, the function F_θ in eq. 9 becomes $1 + \nu$, and transverse shrinkage is given by:

$$S_t = (1+\nu)C_1\left(\frac{A}{h^2}\right)\log_e\left\{\frac{7.8(A+A')}{w_0}\right\} + (1+\nu)C_2\sqrt{\frac{A}{h^2}} \qquad (27)$$

The magnitude of C_1, C_2 and w_0 in Table 2 being used and groove of back chipping being assumed to be a semicircle of radius 6 mm (or $A' = 0.565$ cm²), S_t is obtained as shown in Fig. 14. From this the magni-

* See Appendix II.

† Among these specimens, data of circular-ring type specimens and slit-type specimens were quoted from Dr. Kihara's papers.[8,9]

‡ S_{tf} in each specimen was calculated from eq. 9 in Table 2.

tude of shrinkage due to butt-welding can be predicted for a given thickness of plate and given welding conditions.

Figure 15 shows some examples of comparison between measured results in an oil tanker (Dwt. 20,000 tons) and calculated curves from eq. 27. In these calculations, the magnitude of C_1, C_2 and w_0 was modified according to the magnitude of welding current in each case by using the following relations (see Table 2):

$$C_1 \propto I, \quad C_2 \propto \sqrt{I}, \quad w_0 \propto I \quad (28)$$

It is known from Fig. 15 that the calculated curves almost agree with the measured results.

Degree of External Restraint of Butt-Welded Joints when Erecting Ship Assemblies on Building Ways

This problem has been considered to be important in the construction of ships from the standpoints of residual welding stress and cracking. As pointed out previously, S_l/S_{lf} is decided only by the restraint coefficient—see Fig. 12. Therefore, the magnitude of shrinkage due to welding in erecting ship assemblies being measured and it being compared with the shrinkage in unrestrained welded joint obtained by eq. 27, the degree of external restraint will be predicted from Fig. 12. Figure 16 shows the data of S_l/S_{lf} in a cargo boat (Dwt. 10,000 tons) and an oil tanker (Dwt. 20,000 tons).[11] Here the restraint coefficient obtained from Fig. 12 is also shown on the ordinate of the right side. It can be concluded that the degree of external restraint will be comparatively small in welding of ship assemblies on building ways.

Control of Distortion in Web Plate of Welded Built-up Girder Due to Welding of Stiffeners

In a welded built-up girder as shown in Fig. 17, distortion will be produced in web plate due to welding stiffeners. These welded joints are under external restraint as shown in Fig. 11 (b). Let space of stiffeners and height of web be denoted by l_1 and l_2 respectively, then the restraint coefficient is given by eq. 26. If additional restraining members are tack welded as shown in Fig. 17 and web plate is divided into $(n+1)$ small panels, then the restraint coefficient will be increased as follows:

$$p = \frac{E}{1-\nu^2} \cdot \frac{\pi^2}{8l_1} \left\{ 1.5 + 1.975(n+1)^2 \left(\frac{l_1}{l_2}\right)^2 + 0.927(n+1)^4 \left(\frac{l_1}{l_2}\right)^4 \right\} \quad (29)$$

And the decrease of distortion will be expected with the increase of n.

Figure 18 shows the maximum deflection of web plate for $n = 0$ and $n = 1$.[12] Calculated curves in Fig. 18 were obtained from eq. 5 in Table 2 and eq. 29. These equations will be utilized for the determination of arrangement of additional restraining members.

Conclusion

1. There are many factors which affect shrinkage distortion, but they are classified into two groups—factors relating to welding heat and factors relating to external restraint.

2. As parameters relating to welding heat, the following three were obtained:

(a) Temperature rise near the weld metal: $Q = \eta VI/\phi^{\alpha} \cdot \sqrt{v}$.

(b) Number of passes to make a completed joint: $N = W/w_0$.

(c) Ratio of heat supplied in backing pass to the one in finishing pass of butt-welded joints: W_A/W_B.

The relation between these parameters and factors relating to welding heat is shown in Table 1 by open circle. Using the table, systematic study can be performed on the problems of shrinkage distortion.

3. Shrinkage distortion in unrestrained welded joints is generally given by eq. 9. Shrinkage distortion of weld metal by itself—that is to say, inherent shrinkage ξ_1 and inherent angular change δ are obtained as functions of parameters Q, N and W_A/W. They are summarized in Table 2, while function F_s in eq. 9 is obtained by using elastic theory. Table 2 being used, quantitative study can be performed on shrinkage distortion.

4. Shrinkage distortion under external restraint is generally given by eq. 21. The function F_c in eq. 21 is decided only by the degree of external restraint, and it is independent to the other conditions. The restraint coefficient (p) for transverse shrinkage and angular change is decided by elastic theory for given size and type of specimen. Some examples are given by eqs. 22–26. These equations being used, the magnitude of the function F_c can be obtained from Figs. 12 and 13.

5. From the results of this study, it can be concluded that shrinkage distortions are generally expressed by the following relations:

$$\text{Shrinkage distortion} = \left(\xi_1 \text{ or } \delta\right) \times F_s \times F_c.$$

6. By applying the results obtained in this paper, many problems on shrinkage distortions will be quantitatively resolved. Some examples of them are shown at the end of this paper.

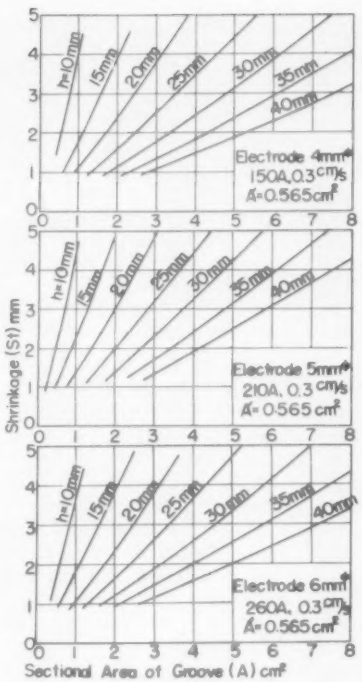


Fig. 14—Transverse shrinkage in unrestrained butt-welded joint versus welding conditions curves

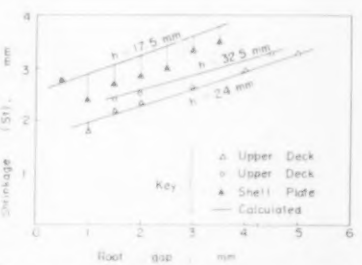


Fig. 15—Comparison between measured values of shrinkage in butt-welded joints of ship assemblies and calculated ones

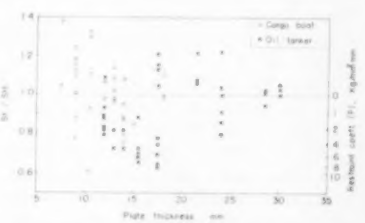


Fig. 16—S_l/S_{lf} and restraint coefficient in welding ship assemblies on building ways

APPENDIX I

If heat radiation from the surface of plate can be neglected, temperature rise H in quasi-stationary state is given by:

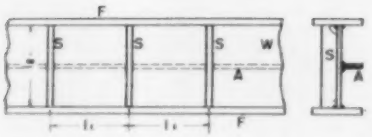


Fig. 17—Welded built-up girder

$$H(x'', y, z) = \theta(x'', y) + \sum_n \theta_n(x'', y) \cos \frac{n\pi z}{h} \quad (30)$$

where (x'', y, z) is a coordinate system moving with the heat source. Let the shrinkage in the neutral surface of the plate due to average temperature rise θ be considered. Average inherent strains throughout plate thickness being denoted by $\bar{g}_x$, $\bar{g}_y$, $\bar{g}_{xy}$ and it being assumed that $\bar{g}_x = \bar{g}_y \equiv \bar{g}(y)$ and $\bar{g}_{xy} = 0$, then particular solution of stress function at any point except for weld line is given by:

$$\Phi = \frac{E\boxed{\bar{\varepsilon}_1}}{2\pi} \int_0^L \log r' dx'$$

(see Fig. 4 (a).)

in which $\boxed{\bar{\varepsilon}_1}$ is represented by:

$$\boxed{\bar{\varepsilon}_1} = -\int_{-\bar{b}/2}^{\bar{b}/2} \bar{g}(y')dy' = -\bar{b} \times$$

(average inherent strain)

where

$$\bar{b} = \frac{1}{h}\int_0^h b_z dz$$

It was assumed that the average inherent strain has equal magnitude and opposite sign to average thermal expansion at the instant when Θ_p isotherms is most extended. The magnitude of this average thermal expansion will be changed by welding heat. However, it can be confirmed by numerical calculation that the change is comparatively small in some range of welding current for a given electrode, and it can be assumed as represented by the first of eqs. 8.

As for the second of eqs. 8, the following fact which is obtained from ordinary bending theory of flat plate may be utilized. The slope (δ_x, δ_y) due to bending of plate of which temperature distribution is represented by eq. 30 may be given by:

$$(\delta_x, \delta_y) = \frac{2}{h}(u_x, u_y)$$

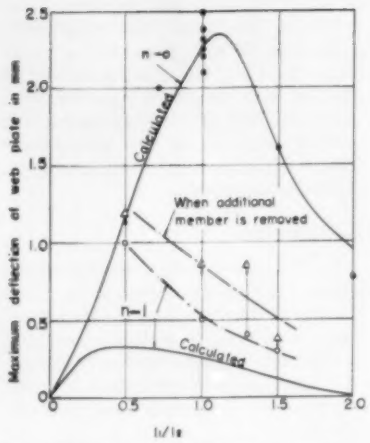


Fig. 18—Effect of additional restraining member on the maximum deflection of web plates

where (u_x, u_y) is displacement in the neutral surface of a plate of which temperature distribution is given by:

$$\bar{\theta}(x'', y) = -\frac{6}{h^2}\int_{-h/2}^{h/2} \Theta z' dz'$$

Then the relation of the second of eqs. 8 can be obtained by the analogous way to before.

APPENDIX II

Let the Type 1 in Fig. 11 be considered. Average angular change along y-axis due to uniform bending moment M_x acting on the axis can be obtained by applying principle of virtual displacement. (See Fig. 11).

Putting the deflection of plate

$$w = \delta_0 x \cos \frac{\pi y}{l_2}$$

then strain energy of the plate is given by:

$$V = D\delta_0^2 \left\{ \frac{\pi^4}{96}\left(\frac{l_1}{l_2}\right)^3 + \frac{(1-\nu)\pi^2}{4}\left(\frac{l_1}{l_2}\right) \right\} \quad (31)$$

Virtual work due to a virtual displacement $\delta w = \delta[\delta_0 x \cos(\pi y/l_2)]$ is given by:

$$M_x dy' \delta\left(\delta_0 \cos \frac{\pi y'}{l_2}\right)$$

And

$$M_x dy' \delta\left(\delta_0 \cos \frac{\pi y'}{l_2}\right) = \frac{\partial V}{\partial \delta_0} \cdot \delta(\delta_0)$$

Substituting from eq. 31

$$M_x \cos \frac{\pi y'}{l_2} dy' = D\delta_0 \left\{ \frac{\pi^4}{48}\left(\frac{l_1}{l_2}\right)^3 + \frac{(1-\nu)\pi^2}{2}\left(\frac{l_1}{l_2}\right) \right\}$$

$$\equiv D\delta_0 C$$

δ_0 due to total bending moment acting on y-axis is given by

$$\delta_0 = \frac{M}{DC}\int_{-l_2/2}^{l_2/2} \cos \frac{\pi y'}{l_2} dy' = \frac{2l_2 M_x}{\pi DC}$$

from which

$$w = \frac{2l_2 M_x}{\pi DC} \cdot x \cos \frac{\pi y}{l_2}$$

and average angular change along y-axis is given by

$$\left(\frac{\partial w}{\partial x}\right)_{AV.} = \frac{1}{l_2}\int_{-l_2/2}^{l_2/2} \frac{\partial w}{\partial x} dy = \frac{4l_2 M_x}{\pi^2 DC}$$

$$\therefore M_x = \frac{\pi^2 DC}{4l_2}\left(\frac{\partial w}{\partial x}\right)_{AV.}$$

$\therefore$ maximum bending stress

$$\sigma_x = \frac{Eh}{2(1-\nu^2)} \cdot \frac{\pi^2 C}{4l_2}\left(\frac{\partial w}{\partial x}\right)_{AV.} \quad (32)$$

Putting $(\partial w/\partial x)_{AV.} = 1/h$ and $\sigma_x = p$ in eq. 32, the following relation is obtained;

$$p = \frac{E}{1-\nu^2} \cdot \frac{\pi^2}{8l_2} \left\{ \frac{\pi^4}{48}\left(\frac{l_1}{l_2}\right)^3 + \frac{(1-\nu)\pi^2}{2}\left(\frac{l_1}{l_2}\right) \right\}$$

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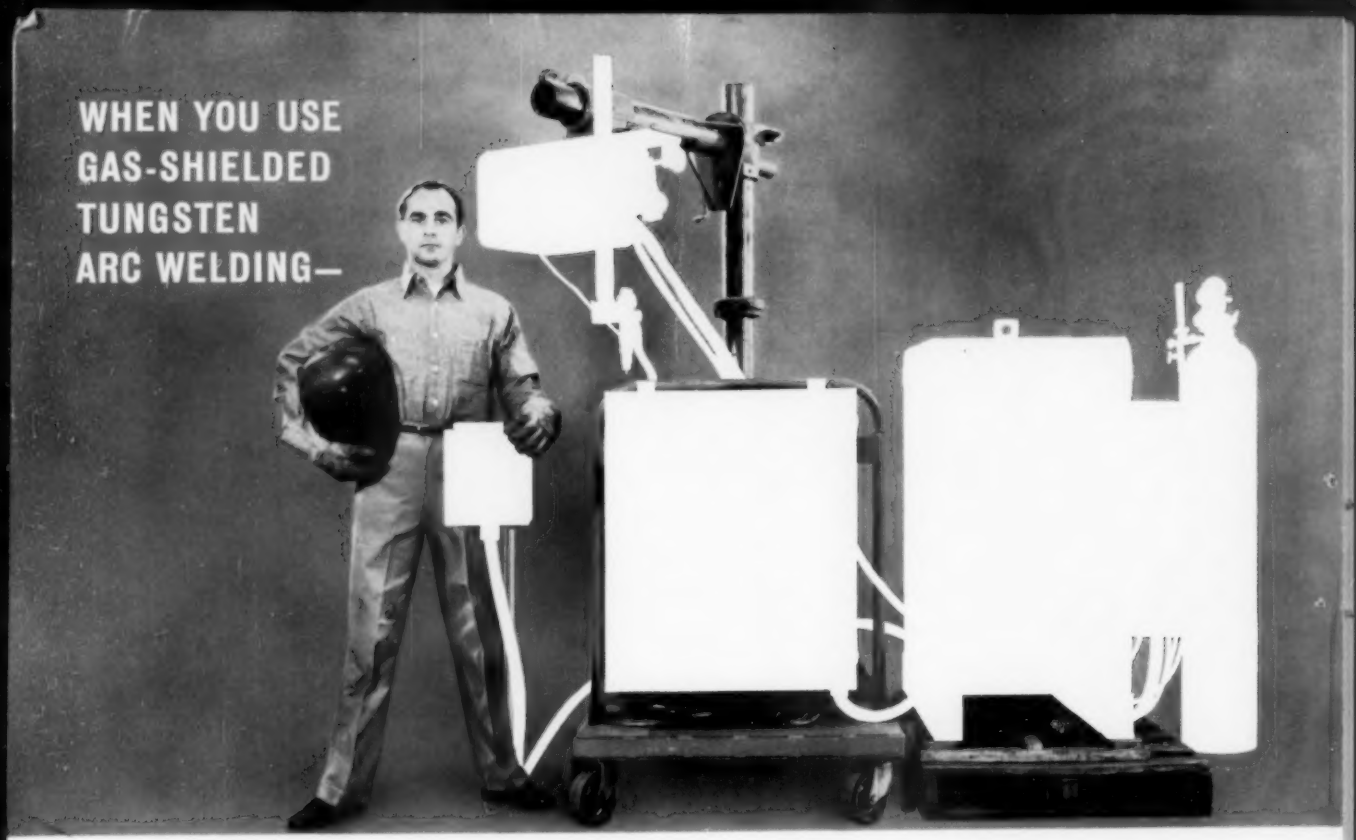

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